Subventions publiques et décisions de production des agriculteurs une analyse microéconomique

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Public Subsidies and Farmers' Production Decisions: A Microeconomic Analysis

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"How selfish soever man be supposed, there are evidently some principles in his nature which interest him in the fortune of others, and render their happiness necessary to him, though he derives nothing from it, except the pleasure of seeing it". **Adam Smith in *The Theory of Moral Sentiments*.**

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Abstract

In the majority of developed countries the agricultural sector has long been shaped by agricultural policies that provide financial support to farmers, enabling them to adapt to changing economic, social and environmental conditions within which they operate. To evaluate these policies and draw recommendations on their design and scope, their impact on farmers' behaviour is regularly scrutinised. The thesis fits into this perspective, first by analysing the linkage between agricultural subsidies and farm technical efficiency, and then by investigating the potential effects of decoupled subsidies on farmers' provision of ecosystem services.

Technical efficiency assesses whether farmers use their production factors in the most efficient way; i.e., if they are able to get the maximum achievable output for a given input level, or to use a minimum level of input to produce a given level of output. The analysis of the subsidy-efficiency nexus is crucial to inform policy-makers on what extent agricultural subsidies affect the efficiency of the use of agricultural production factors. A major issue of the existing literature in this field is the existence of a plethora of empirical applications in which subsidies are often treated in an ad hoc way, due to the absence of clear conceptual guidance. Potentially, this may generate erroneous results. A second issue is that the existing literature is almost exclusively based on a static view of agricultural production decisions. However, the static analysis can only provide a limited view on the subsidy-efficiency nexus since agricultural production decisions are dynamic in nature. In this context, the first objective of the thesis is to improve the understanding on how public subsidies impact farm technical efficiency. To do that, after reviewing the theory regarding the effect of decoupled subsidies on farmers' production decisions in the second chapter of the thesis, a meta-analysis of the empirical findings on the subsidy-efficiency relationship is carried out in the third chapter, and a dynamic model is developed and estimated for French data in the fourth chapter.

In numerous developed countries decoupled subsidies have become the cornerstone of agricultural support policies. The literature regarding their impact on farmers' behaviour is plentiful, but an area has received little attention: the multitasking nature of farming activities. Hence, as a second objective, the thesis aims at investigating the potential effects of decoupled subsidies on farmers' provision of ecosystem services, despite these subsidies not being designed as such. To address this question, borrowing from the multitasking agency theory, a theoretical model is developed and empirically tested on French data in the fifth chapter of the thesis.

The thesis reaches three main conclusions. Firstly, modelling approaches which treat subsidies as additional outputs or which use the subsidy rate (i.e. the ratio of subsidies to farm revenue) as proxy for subsidies, could generate misleading results on the subsidy-efficiency nexus. Secondly, the (detrimental) effect of subsidies on farm technical efficiency is smaller when dynamic aspects are taken into account. Finally, decoupled subsidies could raise farmers' incentives to provide environmental services and ecologically sound productions.

Keywords: Agricultural policy; public subsidies; farms; production decisions; technical efficiency; dynamic efficiency; multitasking agency theory.

Résumé

Subventions publiques et décisions de production des agriculteurs: Une analyse microéconomique

Dans la majorité des pays développés, le secteur agricole a longtemps été façonné par le soutien financier octroyé dans le cadre des politiques agricoles, soutien permettant aux agriculteurs de s'adapter à l'évolution des conditions économiques, sociales et environnementales dans lesquelles ils évoluent. Pour évaluer les politiques et formuler des recommandations sur leur conception et leur portée, leur impact sur le comportement des agriculteurs est régulièrement examiné. La thèse s'inscrit dans cette perspective, d'abord en analysant le lien entre subventions publiques et efficacité technique des exploitations, puis en examinant les effets potentiels des subventions découplées sur la fourniture de services écosystémiques par les agriculteurs.

L'efficacité technique évalue si les agriculteurs utilisent leurs facteurs de production de manière la plus efficace possible; i.e., s'ils sont en mesure d'obtenir l'output maximum réalisable pour un niveau d'input donné, ou d'utiliser un niveau minimum d'input pour produire un niveau donné d'output. L'analyse du lien entre subventions et efficacité technique est cruciale pour informer les décideurs sur la manière dont les subventions publiques affectent l'efficacité de l'utilisation des facteurs de production dans le secteur agricole. Un problème majeur de la littérature existante dans ce domaine est qu'il existe une pléthore d'applications empiriques où les subventions sont souvent traitées de manière ad hoc, en raison de l'absence de cadre conceptuel clair. Potentiellement, cela peut conduire à des conclusions erronées. Un second problème est que la littérature existante est presqu'exclusivement basée sur une vision statique des décisions de production des agriculteurs. L'analyse statique ne peut fournir qu'une vision limitée du lien entre subventions et efficacité puisque les décisions de production des agriculteurs sont essentiellement dynamiques.

Dans ce contexte, le premier objectif de la thèse est d'améliorer la compréhension de l'impact des subventions publiques sur l'efficacité technique des exploitations. Pour ce faire, après avoir examiné la théorie sur l'effet des subventions découplées sur les décisions de production des agriculteurs dans le deuxième chapitre de la thèse, une méta-analyse des résultats empiriques sur la relation entre subventions et efficacité technique est réalisée dans le troisième chapitre, afin de contrôler les effets qui seraient dus aux méthodes utilisées, et un modèle dynamique est développé et estimé sur des données françaises dans le quatrième chapitre.

Les subventions découplées sont devenues le principal instrument de politiques agricoles dans beaucoup de pays développés. La littérature concernant leur impact sur le comportement des agriculteurs est abondante. Cependant, peu de travaux analysent leur rôle dans le cadre d'une agriculture multifonctionnelle. Par conséquent, le deuxième objectif de la thèse est d'étudier les effets potentiels des subventions découplées sur la fourniture de services écosystémiques par les agriculteurs. Pour aborder cette question, en empruntant aux approches multitâches de la théorie de l'agence, un modèle théorique est développé et testé empiriquement sur des données françaises dans le cinquième chapitre de la thèse.

La thèse arrive à trois conclusions principales. Tout d'abord, les approches de modélisation qui traitent les subventions comme des outputs supplémentaires ou qui utilisent le taux de subvention (rapport entre subventions et revenu) comme proxy, peuvent générer des résultats trompeurs sur le lien entre subventions et efficacité technique des exploitations. Deuxièmement, l'effet (négatif) des subventions sur l'efficacité technique des exploitations est plus faible lorsque les aspects dynamiques sont pris en compte. Enfin, les subventions découplées peuvent augmenter les incitations des agriculteurs à fournir des services écosystémiques.

Mots clés : Politiques agricoles; subventions publiques; exploitations; décisions de production; efficacité dynamique; théorie de l'agence multitâches.

Contents

Chapter 1

General introduction

1.1 Background

There is a long tradition of government interventions in the agricultural sector, particularly in most developed countries, to implement policies that provide financial support (public subsidies) to farmers. For instance, agricultural support policies in the United States (US) and the European Union (EU) began respectively in the 1930s and the 1960s. In the last two decades, the EU spent around €50 billion annually on the Common Agricultural Policy (CAP); and this amount represents approximately 40% of the EU budget (Greer, 2013; Anania and Pupo D'Andrea, 2015). Similarly, the US Farm Bill costs annually around €65 billion, in which agricultural subsidies absorb approximately 20% (Johnson, 2007; Johnson and Monke, 2014). Since their inception, these policies have been subject to a continuous reform process to adapt to changing economic, social and environmental conditions within which farms operate. In this perspective, a number of policy instruments have been introduced; and their impact on farmer's production decisions is regularly scrutinised since they often generate unintended consequences (Grant, 2007). In essence, the analysis of their impact on farmers' behaviour is needed to guide their design, their assessment, or to modify their scope. As such, the linkage between public subsidies and farmers' behaviour occupies a central role in agricultural production economics and agricultural policy analysis.

The major reforms of the agricultural support policies consist in a movement from market price supports to coupled direct payments (production-related supports) and decoupled direct payments to farmers. Along with the direct payment schemes, farmers were also encouraged to engage voluntarily in environmentally friendly farming practices through agri-environmental schemes (AES); but it is well known that the degree of uptake is globally low (Guillem and Barnes, 2013; Espinosa-Goded et al., 2013). The market price supports and the production-related supports have been criticised because they influence production decisions without providing adequate price signals. The market price support policies guarantee a minimal fixed price for certain commodities, and thus encourage overproduction and extensive use of resources. The production-related subsidies provide incentives to expand the production of the more subsidised products, and may also provide incentives for extensive resources use. To avoid such effects, production distorting subsidies have been gradually replaced by decoupled subsidies that are granted to farmers without production requirements. In turn, coupled direct payments have not completely disappeared in the EU, since the reforms allow keeping a part of them for some specific farming systems (Rizov et al., 2013; Matthews, 2015).

Overall, theoretical and empirical studies have demonstrated that, even when decoupled, public subsidies could have direct and indirect influence on farmers' behaviour (e.g. Hennessy, 1998; Ciaian and Swinnen, 2009; Just and Kropp, 2013). To enlighten agricultural policy makers and various stakeholders, a clear understanding of the influence of public subsidies requires an examination of the different aspects of farmers' behaviour. In this sense, a vast amount of literature finds evidence for causal links between public subsidies and farmers' decisions to remain in the agricultural sector (Guyomard et al., 2004; Chau and de Gorter, 2005; Ahearn, 2005; Breustedt and Glauben, 2007; Brady et al., 2009 ; Douarin and Latruffe, 2011); the type and the level of production (Guyomard et al., 1996 ; Antón and Le Mouël, 2004; Breen et al., 2005; Serra et al., 2006); the use of production factors, such as land and labour (Tranter et al., 2007; Bougherara and Latruffe, 2010 ; Dupraz and Latruffe, 2015; Lobley and Butler, 2010); investments (Vercammen, 2007; Sckokai and Moro, 2009; Serra et al., 2009; Latruffe et al., 2010; Bojnec and Latruffe, 2011; Kallas et al., 2012); the allocation of family labour to off-farm activities (Woldehanna et al., 2000 ; El-Ostra et al., 2004; Serra et al., 2005; Ahearn, 2005; Ahearn, 2006); farm performance (Serra et al., 2008; Zhu et al., 2010; Kumbhakar and Lien, 2010; Latruffe et al., 2012; Sipiläinen et al., 2014); and farmers' risk attitude (Hennessy, 1998; Sckokai and Antón, 2005; Goodwin and Mishra, 2006; Sckokai and Moro; 2006; Koundouri et al., 2009; Fémenia et al., 2010). In this thesis a particular attention is paid to farm performance, and mainly farm technical efficiency.

Technical efficiency assesses whether farmers use their production factors in the most efficient way; i.e., if they are able to get the maximum achievable output for a given input level, or to use a minimum level of input to produce a given level of output. Therefore, the analysis of the impact of public subsidies on farm technical efficiency is of crucial interest for policy makers, since it could provide information on the extent to which agricultural subsidies affect the efficiency of the use of agricultural production factors. In the literature investigating the impact of public subsidies on farm technical efficiency, it is generally recognised that public subsidies are detrimental to the agricultural sector in the way that they reduce farms' technical efficiency. This conclusion is essentially drawn from empirical results (e.g. Giannakas et al., 2001; Rezitis et al., 2003; Emvalomatis et al., 2008; Bojnec et Latruffe, 2009; Bakucs et al., 2010; Zhu et Oude Lansink, 2010; Zhu et al., 2011; Kumbhakar et al., 2009; Kumbhakar et al., 2014; Sipiläinen et al., 2014). Nevertheless, some empirical studies have shown that positive associations between public subsidies and farm technical efficiency may also exist (e.g. Hadley, 2006; Kumbhakar and Lien, 2010). Even though these mixed results can be explained theoretically (Serra et al., 2008; Zhu et al., 2010; Kumbhakar and Lien, 2010), a closer look at the existing literature on the subsidy-efficiency link reveals the need for new research. First, given the absence of clear conceptual guidance on how to incorporate subsidies in a production efficiency framework, there exists a plethora of models in which the effect of subsidies on efficiency is often treated in an ad hoc way (McCloud and Kumbhakar, 2008). Potentially, this may generate confusing results. Thus, to avoid erroneous understanding on the subsidy-efficiency nexus, it is useful to assess the consistency of the underlying empirical results reported in the literature. In particular, it is important to examine whether the empirical findings are sensitive to the way subsidies are modelled. Another issue of this literature is that it is almost exclusively based on a static view of farmers' production decisions. This gap has to be filled since agricultural production decisions are dynamic in nature (Gardebroek and Oude Lansink, 2008; Serra et al., 2011a). To our knowledge, the paper by Skevas et al. (2012) is the only paper which analyses the subsidy-efficiency nexus in a dynamic framework. However, this paper uses a deterministic two-stage DEA approach relying on a "separability condition" (Simar and Wilson, 2011), which states that the input-output set is not influenced by public subsidies. This assumption is likely to be very restrictive, since it is theoretically demonstrated that public subsidies may influence the input-output space (see Hennessy, 1998; Serra et al., 2006).

The stream of literature that examines the impact of public subsidies on farmers' behaviour via their effect on farmers' risk attitude concludes that decoupled payments may change farmers' risk aversion through a wealth effect (by increasing farmers' income) and an insurance effect (by stabilising farmers' income). In this respect, they could drive production decisions by reducing farmers' risk aversion to engage in risky production activities or by altering their choices in terms of output production and input use. Based on a review of literature, Bhaskar and Beghin (2009) mention that these effects are relatively small (see also Serra et al., 2011b). However, Just and Kropp (2013) have theoretically and empirically demonstrated that, even in the absence of risk aversion, decoupled payments are potentially production distorting in a similar magnitude as production-related subsidies. Their idea is that since some farming activities are not eligible to decoupled payment schemes, this may generate production distortions because farmers have no incentives to respond to market signals if prices (or demand) for non-eligible products increase. In other words, under the decoupled payment schemes, farmers are constrained to produce (if they decide to produce) certain eligible commodities even if the latter are less profitable than non-eligible ones. These findings suggest that the impact of decoupling on farmers' behaviour remains an open debate.

In the debate on the impact of decoupled subsidies on farmers' production decisions, an area that has received little attention is the multitasking nature of farming activities: in addition to food production, farming activities are expected to ensure production of environmental services to society. Although some studies support that adoption of environmentally friendly farming practices could be driven by farmers' environmental attitudes (environmental consciousness) (Anderson, 1990; McCann et al., 1997; Guillem and Barnes, 2013; Karali et al., 2014), many others report that financial incentives also play a crucial role in determining farmers' pro-environmental behaviour (Gasson and Potter, 1988; Morris and Potter, 1995; Wilson, 1997; Crabtree et al., 1998; Macdonald and Johnson, 2000; Wilson and Hart, 2000; Mann, 2003; Fish et al., 2003; Kiptot et al., 2007; Karali et al., 2014). In a similar vein, Kollmuss and Agyeman (2002) point out that even people with high environmental awareness tend to adopt low-cost pro-environmental behaviours. This coincides with the idea of Espinoza-Goded et al. (2013) who state that farmers are reluctant to follow pro-environmental behaviours given high fixed costs associated with them. Additionally, Mann (2003) and Karali et al. (2014) explain pro-environmental behaviours of the vast majority of Swiss farmers by the fact that direct payments allow farmers to cover the underlying costs. In turn, the thesis explores the extent to which environmentally friendly farming practices could be driven by decoupled payments.

1.2 Objectives and research questions

The first objective of the thesis is to improve the understanding on how public subsidies impact farmers' production decisions, with a specific attention on farm technical efficiency. As a second objective, the thesis intends to investigate the potential effects of decoupled subsidies on farmers' provision of productive and environmental services. The thesis addresses three specific research questions:

- **Is there unambiguous evidence on the subsidy-efficiency nexus in the existing empirical literature?** if not, **are there methodological aspects that can explain the discrepancies?**

  The thesis aims at scrutinising the empirical literature that assesses the impact of public subsidies on farm technical efficiency. The first objective is to undertake a systematic review of this literature to provide an overview of the effects reported and to identify the different analytical approaches used. The second objective is to investigate the incidence of analytical choices made by authors (such as the way subsidies are modelled, the type of subsidy considered, the subsidy proxy used, the method employed to compute technical efficiency, the econometric strategy, and the geographical area covered by the study) on the effect (positive, negative, or null) of public subsidies on farm technical efficiency. The analyses allow us to derive stylised facts and to separate structural effects from method-specific effects.

- **Are there any gains in understanding the subsidy-efficiency nexus by moving from static to dynamic modelling?**

  The thesis explores whether dynamic aspects associated with investment decisions improve the understanding on how public subsidies impact farm technical efficiency.

- **Does the multitasking nature of farming activities improve our understanding of the effects of decoupled subsidies on farmers' provision of productive and environmental services?**

  Borrowing from the multitasking agency theory, we provide new theoretical and empirical rationales for the possible incentive effect of decoupled subsidies.

1.3 Analytical approaches

Qualitative and quantitative approaches are used to answer the three research questions outlined above. For the first question, a meta-regression analysis (MRA) approach is used. The MRA is a quantitative method that allows synthesising and evaluating available evidence on a particular research question, in an objective way (Stanley and Jarell, 1989; Becker and Wu, 2007; Borenstein et al., 2009). In essence, it is similar to the well-known regression techniques in which an outcome variable is predicted according to a set of regressors. In MRA, the outcome variable is the effect estimated by a set of primary studies on a given research question, and the regressors are mainly the characteristics of the primary studies that may influence the estimated effects (Thompson and Higgins, 2002). In other words, the MRA allows investigating the extent to which heterogeneity of findings from multiple primary studies can be related to the characteristics of these studies (Harbord and Higgins, 2008).

Concerning the second question, using insights from the well established stochastic frontier approach (SFA) (Kumbhakar and Lovell, 2000; Cuesta et al., 2009; Serra et al., 2011b), the subsidy-efficiency nexus is examined using a dynamic stochastic frontier model and the static counterpart of this model is used as a baseline for comparisons. The SFA allows estimating a frontier of best production practices that envelop the data while assuming the existence of an idiosyncratic error term. Specifically, the thesis develops a dynamic stochastic frontier model that is an extension of the hyperbolic distance function introduced by Cuesta et al. (2009) in which intertemporal production decisions are modelled through investment decisions. A similar approach has been used in Serra et al. (2011b) using a directional distance function. The main difference between the directional distance function and the hyperbolic distance function is that the latter is based on the multiplicative homogeneity property of Shephard's (1953; 1970) distance function, while the former is characterised by the translation property which is the additive analogue of the multiplicative homogeneity property (see Färe et al., 2005; Cuesta and Zofío, 2005; Cuesta et al., 2009, for more details). The stochastic frontier approach used in the thesis models public subsidies neither as inputs nor as outputs, but as contextual drivers that may influence the efficiency with which inputs are transformed into outputs.

As regards the last question, borrowing from the multitasking agency theory (Holmstrom and Milgrom, 1991), the thesis develops a theoretical model which is then empirically tested using an extended version of the seemingly unrelated regression (SUR) model (Zellner, 1962; Roodman, 2011) and a structural model in line with Lacroix and Thomas (2011) and Laukkanen and Nauges (2014). As stated in Macdonald (1984), agency theory "focuses on utilisation of compensation rules (incentives) with which one player, the Principal, seeks to motivate another, the Agent, to choose his activities in a way advantageous to the Principal". In contrast to the basic agency theory which concentrates on the realisation of a single task, the multitasking agency theory initiated by Holmstrom and Milgrom (1991) assumes that either the Principal has several different tasks for the Agent to perform, or that the Agent's main task is multidimensional. In this case, when effort on one task raises the cost of effort on other tasks, the Agent will focus his effort on measurable and compensated tasks at the expense of others. This situation raises the problem of multitasking which refers to a challenge for the Principal to design incentive systems that allow avoiding this kind of substitution between tasks. The multitasking issue could appear in agricultural production decisions. Farmers are expected to produce ecologically sound outputs and ecosystem services. Therefore, if farmers are paid for a given measurable environmental service, they would neglect the other services or the production of ecologically sound outputs depending on the costs to produce them.

The theoretical model developed in the thesis highlights that a mixed payment system (with more decoupled subsidies) could reduce the multitasking issue in farming activities. In this model, the Principal is a social planner (the government), that gives some incentives to an Agent (the farmer) to choose some specific ecosystem services (production or environmental services) through a contract. The Principal is assumed to maximise a social welfare function. The Agent (the farmer) is assumed to maximise a strictly concave and continuously differentiable utility function where the arguments are the profit generated by the production process, the subsidies, and a parameter that captures farmer's benevolence. In this model, we derive some testable propositions on the optimal compensation scheme in the contract (subsidies structures, i.e. coupled and decoupled) and the farmer choice regarding the different ecosystem services at the farm level. To test the theoretical model, an extended SUR model is used (see Roodman, 2011). This model accounts for continuous, dichotomic and polytomic decision variables. Additionally, some aspects of the theoretical model are empirically tested using a structural model in line with Lacroix and Thomas (2011) and Laukkanen and Nauges (2014).

1.4 Data used

For the meta-regression analysis, data collected from a systematic review of studies assessing the relationship between public subsidies and technical efficiency in the agricultural sector, were used. The search of papers on this issue was conducted first through the main computerised databases such as Econlit, Web of Science (WoS), Web of Knowledge (WoK), JSTOR, Econpapers, Science Direct, RepEc (IDEAS) and Google Scholar, combining in several search formulae the following keywords: 'subsidies' or 'support', alone or with 'public', 'government', 'CAP', 'Single Farm Payment', 'pillar 1', 'pillar 2', 'agricultural', 'EU', or 'farm bill'; together with 'efficiency', technical efficiency', 'economic efficiency', 'farm efficiency', 'productive efficiency', 'farm performance' or 'economic performance'. This literature search was completed by exploring the reference lists of the papers obtained through the first search. Published and unpublished studies is included in the meta-analysis if they provided sufficient information on the data used, the estimated effect, and their analytical method. The basic dataset contained 195 observations (that is, 195 distinct results about the effect of subsidies) extracted from a set of 68 studies which were carried out during the period 1986 to 2014.

Regarding the other empirical applications, accounting data of a sample of farmers in the French region Meuse is used. This region is located in north-west France in the main administrative region of Lorraine. The original dataset available covers the period from 1992 to 2011 and contains 12,455 (farm-year) observations. These data concern farmers who have voluntarily enrolled in a regional accounting office so as to be guided in their management practices. The Meuse data are very similar to FADN data; in fact, they are used to produce FADN[1] data, but they are a bit more detailed than FADN data (they contain a few more variables). This database mainly contains information on farm production structure, farm financial results, and agricultural subsidies. This includes utilised agricultural area, labour, intermediate inputs, capital and investments, crop production, and livestock production. Similarly to all farms in France and in the EU, the sampled farms received subsidies from the EU Common Agricultural Policy (CAP). Farms were entitled to receive subsidies that took various forms: (i) Single Farm Payments (SFP) which are lump-sum subsidies per hectare of land used whatever the type of production on this land, even if there is no production, on the condition that the farmer complies

[1]The Farm Accountancy Data Network (FADN) is a widely-used dataset for evaluating farming activities in the European Union and the impacts of the Common Agricultural Policy

with environmental cross compliance requirements; (ii) subsidies coupled to production, in the way that the farm receives direct payments for every hectare of a specific crop (e.g. wheat) and every head of a specific livestock (e.g. beef cattle); (iii) agri-environmental subsidies received for voluntary implementation of agri-environmental friendly practices on the farm (i.e. AES); (iv) investment subsidies; (v) lump-sum subsidies as a compensation for being located in a less favourable area.

1.5 Main contributions

The main contributions of the thesis to the existing literature are threefold.

- From a methodological point of view, the thesis draws recommendations that could be helpful in further studies on farm technical efficiency and subsidies. For example, the thesis recommends that investigating the effect of subsidies on farmers' technical efficiency should rely on a careful modelling of subsidies. The meta-regression analysis shows that when subsidies are modelled as outputs, a positive subsidy-efficiency nexus is commonly found. This positive association is potentially erroneous because modelling subsidies as outputs artificially inflates the value of total outputs, while there is no corresponding change in input use. Additionally, it shows that when subsidies are proxied by the subsidy rate (i.e., the ratio between the total subsidies received by farmers and farm revenue or farm output in values) the subsidy-efficiency nexus is commonly negative. This approach may also lead to misleading results because it corresponds, in a sense, to the regression of a given variable on its inverse, since the variable generally used as output in the subsidy-efficiency analysis is farm revenue.
- From an empirical point of view, the thesis highlights that, in comparison with the dynamic framework, the commonly used static framework overestimates the marginal effects of public subsidies on farm technical efficiency. This finding may be interesting for policy makers, since it reveals that the (negative) impact of public subsidies on technical efficiency is smaller when dynamic aspects are taken into account. However, even though the estimated effects are significant at the 1% level, the underlying marginal effects estimated are negligible. This suggests that the marginal effects of the subsidies on farm technical efficiency should be calculated, instead of interpreting only the sign and the significance of the effects, which is a common practice in the existing empirical literature.
- From a theoretical perspective, the thesis provides new rationale for the potential effects of decoupled subsidies on farmers' provision of productive and environmental services. Particularly, by considering the multitasking nature of farming activities, it shows that

subsidising farmers with decoupled payments could raise their incentives to provide environmental services and ecologically sound production. In a sense, this result suggests that the technical efficiency framework, which generally indicates that public subsidies are detrimental to the agricultural sector's performance, could mask some interesting virtues of the decoupled payments.

1.6 Outline

The thesis is organised into **six chapters** including this general introductory chapter and a concluding chapter. The thesis is a compilation of four articles presented in chapter form. **Chapter 2** provides a succinct formal review of the mechanisms through which decoupled subsidies influence farmers' production decisions and discusses their implementation in applied production analysis. **Chapter 3** presents a meta-regression analysis of the empirical findings reported in the literature on the subsidy-efficiency nexus. **Chapter 4** examines the implications of a dynamic framework for analysing the subsidy-efficiency nexus, by developing and estimating a dynamic stochastic frontier model in addition to the static counterpart. In **chapter 5** the thesis develops and tests a theoretical model based on the multitasking agency theory in order to investigate the role of decoupled subsidies on the provision of environmental services. The last **chapter** draws some concluding comments, along with a summary of the main findings of the thesis, the limits and some suggestions for further research.

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Chapter 2

Coupled subsidies, production decisions, and productive efficiency: A synthetic theoretical and methodological review

2.1 Introduction

To avoid production distortions due to coupled subsidies, decoupled payments have become one of the key instruments of recent agricultural policies, since they have been presented as production neutral supports. However, based on the intuition that any agricultural policy instrument may influence farmer's behaviour (Cahill, 1997), the neutrality of the decoupled payments is being questioned. Consequently, a growing body of literature explores the mechanisms through which decoupled payments may impact production decisions. Theoretically, identified mechanisms can be grouped under four categories, namely, risk-related effects when farmers have non-neutral risk preferences and face uncertainty related to output and/or prices, static effects under liquidity constraints, dynamic effects related to investment decisions, and effects related to labour decisions (allocation of family labour to off-farm activities) (Antón, 2001). This chapter intends to provide a succinct formal review of these mechanisms and discuss their implementation in applied production analysis. The appealing feature of the chapter is that it jointly treats the theoretical and the empirical literature on subsidisation-production decisions nexus. Thus it contributes to a global understanding of the influence of decoupled subsidies on production decisions. Its theoretical part is built mainly on the paper by Moro and Sckokai (2013), but it describes some mathematical aspects more explicitly.

The remainder of the chapter is organised as follows. Section 2.2 lays out the theoretical models. Section 2.3 presents the empirical models. Section 2.4 draws some concluding remarks.

2.2 Theoretical models

2.2.1 Risk-related effects

Agricultural production is a risky process, since production decisions are subject to market risk due to price volatility and production risk due to unforeseen weather conditions. Thus agricultural price can be represented as $\widetilde{p} \sim \left(p, \sigma_p^2\right)$ and output production can be seen as $\widetilde{y} \sim \left(y, \sigma_y^2\right)$, where the variances $\left(\sigma_y^2, \sigma_p^2\right)$ are indicators of riskiness. A risk neutral producer abstracts from price and output volatility. Hence, under risk neutrality and decoupled payments, production theory assumes that producers act to maximise their expected profit given the existing production technology:

$$\begin{gathered} \max_x \pi = py - wx + S \\ s.t \ (x, l, y) \in T \end{gathered} \tag{2.1}$$

where π denotes expected profit; p stands for mean output price, y is the mean output, x is a vector of variable inputs with related prices w, l are fixed or quasi-fixed inputs, S denotes the amount of decoupled payments received, and T stands for the existing production technology. The production technology is represented by a production function $y = f(x; l)$. For each variable input j, the first order condition (FOC) is as follows:

$$\frac{\partial f}{\partial x_j} = \frac{w_j}{p} \tag{2.2}$$

Expression [2.2] indicates that the risk neutral farmer chooses the set of inputs x that maximises his expected profit, such that the value of the input marginal productivity $\left(p\frac{\partial f}{\partial x_j}\right)$ is equal to the input price (w_j). Hence under this framework, input choice and thus production choice is not influenced by decoupled payments. However, the explanatory power of the previous framework is quite limited, since studies on producers' attitude toward risk have generally found that farmers are risk-averse (See Makki et al., 2004, for a comprehensive discussion).

If farmers have non-neutral risk preferences U, they maximise the expected utility of their profit given the existing production technology. In the presence of uncertainty, the predominant approach to representing production technologies is the stochastic production function introduced by Just and Pope (1978; 1979): $y = f(x; l) + g(x; l)\,\xi$, with $\xi \sim N(0, 1)$. In the Just-Pope formulation, the first component $f(.)$ is the mean production function and the second component $g(.)$ is the output variance function. The output variability is assumed to depend on input use. Here we abstract from market risk, since as pointed out by Pope and

Kramer (1979), for many sectors of an economy (particularly those involving biological growth) production risk may overcome market risk. Hence, the risk-averse producer's problem in the presence of uncertainty is given by:

$$\begin{aligned}\max_x E\left[U(\pi)\right] &= \max_x E\left[U(py - wx + S)\right] \\ &= \max_x E\left[U(pf(x,l) + pg(x;l)\xi - wx + S)\right]\end{aligned} \tag{2.3}$$

Where U is a proper von Neumann-Morgenstern utility function (Moro and Sckokai, 2013). Using the chain rule, the first-order conditions (FOCs) associated with the optimal choice of inputs is given by:

$$E\left[U^{'}(\pi) \times p\frac{\partial f(.)}{\partial x_j} + p\frac{\partial g(.)}{\partial x_j}\xi - w\right] = 0 \tag{2.4}$$

Taking the expectations and then dividing by $E\left[U^{'}(\pi)\right]$, the FOCs in [2.4] becomes:

$$\begin{aligned}\frac{\partial f(.)}{\partial x_k} &= \frac{w_k}{p} - \frac{\partial g(.)}{\partial x_j} \times \frac{E\left[U^{'}(\pi)\xi\right]}{E\left[U^{'}(\pi)\right]} \\ &= \frac{w_k}{p} - \theta(.)\frac{\partial g(.)}{\partial x_j}\end{aligned} \tag{2.5}$$

Where $\theta(p, w, S) = \frac{E\left[U^{'}(\pi)\xi\right]}{E\left[U^{'}(\pi)\right]}$ is an additional term in the FOCs which represents the risk attitude of the producer and thus captures the impact of risk on the optimal choice of inputs. Consequently, denoting $\alpha = (w, p, \sigma_y, S)$ the vector of the parameters of the input choice $x = x(\alpha)$, the FOCs can be seen as an implicit function, and can be rewritten as follows:

$$\psi_j(x(\alpha); \alpha) = \frac{\partial f}{\partial x_j} = \frac{w_j}{p} - \theta(.)\frac{\partial g(.)}{\partial x_j} \tag{2.6}$$

Expression [2.6] indicates that the input marginal productivity is an implicit function of input prices w, output price p, output variability σ_y, and decoupled subsidies S. The impact of $\alpha = (w, p, \sigma_y, S)$ on input use is given by totally differentiating expression [2.6] with respect to $\alpha = (w, p, \sigma_y, S)$:

$$\frac{\partial \psi}{\partial \alpha} + \frac{\partial \psi}{\partial x} \times \frac{\partial x}{\partial \alpha} = 0 \tag{2.7}$$

This implies that $\frac{\partial x}{\partial \alpha} = -\left(\frac{\partial \psi}{\partial x}\right)^{-1}\left(\frac{\partial \psi}{\partial \alpha}\right)$, where ψ is the vector of the j FOCs, and $\frac{\partial \psi}{\partial x}$ denotes the Hessian matrix of the optimisation problem and it is thus negative. It follows that the effect of decoupled subsidies on input use is given by:

$$\frac{\partial x}{\partial S} = \left(\frac{\partial \psi}{\partial x}\right)^{-1}\left(\frac{\partial \psi}{\partial S}\right) \tag{2.8}$$

Expression [2.8] highlights that decoupled subsidies may impact input use. However, from this expression it is difficult to draw expectations on the sign of the impact, since it depends on the magnitude of the risk-aversion, the risk-input nexus, and the signs of the non-diagonal elements of the Hessian matrix (interaction of input uses). That is why the theoretical literature uses a simplified framework of one input and one output to conduct the comparative statics (see Serra et al., 2006). In this line, for univariate framework the sign of $\frac{\partial x}{\partial S}$ depends mainly on the sign of $\frac{\partial \psi}{\partial S}$, since $\frac{\partial \psi}{\partial x} < 0$. Using the chain rule from expression [2.6], $\frac{\partial \psi}{\partial S}$ is given by:

$$\frac{\partial \psi}{\partial S} = -\frac{\partial \theta}{\partial \pi} \times \frac{\partial \pi}{\partial S} \times \frac{\partial g}{\partial x} \tag{2.9}$$

From expression [2.9], it follows that $\frac{\partial x}{\partial S} < (>) [=] 0$ under DARA(IARA)[CARA][1] preferences for a risk-increasing input. Likewise, for a risk-reducing input $\frac{\partial x}{\partial S} > (<) [=] 0$ DARA(IARA)[CARA] preferences. Notice that considering both market and production risk and assuming $cov\,(p, y) = 0$, Serra et al. (2006) found that for a risk-reducing input the impact of decoupled subsidies is ambiguous. One should also notice that the assumption $cov\,(p, y) = 0$ may not hold in market equilibrium. Thus, as in Hennessy (1998), one can conclude that decoupled payments are not production neutral. In the presence of uncertain production conditions, they influence production decisions of a risk-averse farmer by inducing wealth effect or insurance effect. The wealth effect holds under decreasing absolute risk aversion (DARA) preferences. That is, under DARA preferences, decoupled subsidies impact production decisions by increasing farmers' wealth and thus by decreasing their absolute risk-aversion coefficient. The insurance effect holds under constant absolute risk aversion (CARA) preferences. That is, under CARA preferences, decoupled subsidies influence production decisions in the sense that they reduce income variability.

2.2.2 Static effects under liquidity constraints

In the static context, decoupled payments may influence production decisions through a liquidity effect, even in the absence of risk aversion. This is an important channel to theoretically

[1]DARA: decreasing absolute risk aversion; CARA: constant absolute risk aversion; IARA: Increasing absolute risk aversion

understand how decoupled subsidies impact production decisions, given that farmers often face binding credit constraints (Lee and Chambers, 1986; Swinnen and Gow, 1999; Blancard et al., 2006; Latruffe et al., 2010) and that decoupled payments may induce a relaxation of such constraints (Vercammen, 2007; Ciaian and Swinnen, 2009; Latruffe et al., 2010). Ciaian and Swinnen (2009) argue that if decoupled subsidies are received at the beginning of the growing season, they can be used directly to pay for variable inputs; but if they are received at the end of the season, they can serve as collateral for short-term credits at the beginning of the growing season. Formally, the static effects of decoupling without risk aversion can be analysing using the expenditure-constrained profit-maximisation model developed by Lee and Chambers (1986) and extended by Ciaian and Swinnen (2009). Alternatively, this can be also analysed using the indirect production function approach which describes output maximisation given the existing technology and the available budget for purchasing variable inputs (Kumbhakar and Bokusheva, 2009). Under the expenditure-constrained profit-maximisation framework, the producer problem can be expressed as follows:

$$\max_{x} \pi = py - wx : \ wx = E, \ (x, l, y) \in T \tag{2.10}$$

where $wx = E$ denotes the binding expenditure constraint faced by the producer, with E the budget available for purchasing variable inputs. The production technology is represented by a production function $y = f(x; l)$. From expression [2.10], the first order conditions for the variable inputs x are given by: $p\frac{\partial f}{\partial x} = (1 + \lambda) w$, where $\lambda > 0$ denotes the Lagrange multiplier. Consequently, it follows that the value of the marginal productivity of the variable inputs is higher than their marginal prices. This implies that producers can increase input use to increase their production and thus increase their profit. However, if producers face binding expenditure constraints and the credit market is imperfect, they do not have the possibility to use the optimal quantity of inputs. Hence, in the presence of decoupled subsidies, which can directly or indirectly serve to alleviate credit constraints (Ciaian and Swinnen, 2009), the producer problem becomes:

$$\max_{x} \pi = py - wx + S : \ wx = E + \rho S \tag{2.11}$$

where $\rho \in]0, 1]$ indicates the extent to which decoupled subsidies are used to remove or reduce credit constraints. The Lagrangian for the problem is given by:

$$L = py - wx + S + \lambda (E + \rho S - wx) = pf(x, l) - wx + S + \lambda (E + \rho S - wx) \tag{2.12}$$

The FOCs are given by:

$$\begin{aligned}\frac{\partial L}{\partial x} &= p\frac{\partial f(.)}{\partial x} - w - \lambda w = 0 \\ \frac{\partial L}{\partial \lambda} &= E + \rho S - wx = 0\end{aligned} \tag{2.13}$$

Solving the FOCs [2.13], the use of the inputs can be written as a function of the exogenous variables:

$$x^* = x(E, S, p, w) \tag{2.14}$$

Expression [2.14] indicates that decoupled subsidies may influence input use, even in the absence of risk aversion.

2.2.3 Dynamic effects through investment decisions

Given the stochastic and dynamic nature of the agricultural production process, it may be useful to examine the influence of decoupled payments on production decisions using a stochastic dynamic analytical framework. The stochastic dynamic framework is suitable, since it accounts for intertemporal choices, or for the link between current production decisions and future production possibilities. Intuitively, in a long-run perspective, decoupled subsidies may influence farmers' production decisions by impacting their capacity to invest or to adopt innovations (Hennessy, 1998; Sckokai and Moro, 2009). In this line, dynamic effects of decoupled payments on production decisions are commonly investigated through investment decisions. Considering the dual model of investment developed by Sckokai (2005), the intertemporal problem of a producer who maximises his discounted utility over an infinite horizon, under equation of motion for capital is given by:

$$J\left(r, \pi_0, \bar{p}, w, c, S, \sigma_\pi^2, k\right) = \max_{I,x,y} \int_0^\infty e^{-rt} U\left(\pi, \sigma_\pi^2\right) \quad s.t.\ \dot{k} = (I - \delta k) \tag{2.15}$$

where $U(.)$ denotes the farmer's utility function; its arguments are the farm's wealth $\pi = \pi_0 + py - wx - ck + S$ and its variance σ_π^2 which accounts for production and market risks. While r is the discount rate; k is the units of capital stock; $\dot{k}$ denotes the derivative of capital path with respect to time; I stands for the gross investment in capital; and δ represents the depreciation rate of the capital. Regarding the definition of the farm's wealth, π_0 represents the initial wealth; c is the rental price of the capital; S stands for the decoupled payments; and y represents the output produced. The output production function is given by: $y = f(x, k, I) + \xi$, where ξ is the usual idiosyncratic error term. The Hamilton-Jacobi-Bellman (HJB) equation associated to the optimisation programme [2.15] can be stated as follows:

$$rJ(.) = \max_{I,x,y} \{U(.) + J_k(I - \delta k)\} \tag{2.16}$$

where J_k stands for the first derivative of J with respect to capital. The first derivatives of the HJB equation with respect to output and input prices yield the following system of equations for respectively investment demand, output supply, and variable input demand:

$$\begin{array}{l} \dot{k}(r, \pi_0, \bar{p}, w, c, S, \sigma_\pi^2, k) \\ y(r, \pi_0, \bar{p}, w, c, S, \sigma_\pi^2, k) \\ x(r, \pi_0, \bar{p}, w, c, S, \sigma_\pi^2, k) \end{array} \tag{2.17}$$

Expression [2.17] shows that, in a long-run perspective, investment and production decisions are influenced by decoupled payments.

2.2.4 Potential effects on labour decisions

Given its wealth effect, public subsidies (mainly decoupled subsidies) may also influence farmers' labour decisions. A comprehensive literature review on this issue can be found in Dupraz and Latruffe (2015). But here, briefly, we can mention that:

- Agricultural subsidies can make farming more profitable than off-farm activities of farmers. In this sense, they may allow preserving or increasing the working time allocated to agricultural activities. This effect is predicted mainly for coupled subsidies (El-Osta et al., 2004; Ahearn et al., 2006). In turn, the decoupled subsidies should, a priori, reduce farm work in favour of leisure, because they increase the income of farm households without requiring production activities (El-Osta et al., 2004). However, it must be noticed that empirical results are rather mixed (Ahearn et al., 2006; Mattas et al., 2008; Petrick and Zier, 2011; Dupraz et Latruffe, 2015).
- The effect on technical efficiency is ambiguous. Family labour that would be allocated to off-farm activities could be replaced by hired labour that could be paid through public subsidies, and the technical efficiency would thus not change. However technical efficiency would be reduced if hired labour is not as efficient as family labour; this may occur

because, as indicated in Dupraz and Latruffe (2015), family labour and hired labour are not necessarily substitutes. Family labour is allocated essentially to management tasks while hired labour is rather allocated to technical tasks.

2.3 Empirical models

From an empirical point of view, the analysis of the impact of decoupling on production process is a challenging task, since there is no unified framework on this issue (Moro and Sckokai, 2013). A number of different approaches have been proposed. These approaches include several partial and general equilibrium models (Burfisher et al., 2000; Roe et al., 2002; Gohin, 2006), linear programming setup (Breen et al., 2005; Shrestha et al., 2007), and several econometric frameworks (Goodwin and Mishra, 2005; Serra et al., 2005; Sckokai and Moro, 2006; McCloud and Kumbhakar, 2008; Kallas et al., 2012; Mary, 2013; Rizov et al., 2013). Regarding the theoretical framework reviewed in the previous section (which is mainly at farm level), Moro and Sckokai (2013) argue that the econometric approaches are suitable. Hence, here we consider the econometric approaches by emphasising the modelling of production decisions under the conventional production theory and under the productivity and efficiency framework.

2.3.1 Production decisions modelling under traditional production theory

The conventional production theory assumes that producers are successful optimisers. Also, assuming that producer's input use decisions result from an optimisation programme, in the static context the impact of decoupled subsidies on the production process is commonly investigated (i) indirectly through the estimation of the farmer's risk-aversion coefficient (Hennessy, 1998; Koundouri et al., 2009), (ii) directly by using regression techniques to relate decoupled payments to crop acreage decisions, land acquisition, farmers' labour-leisure decisions, value of farm's outcome, financial structure and other farm's characteristics (Adams et al., 2001; Dewbre and Mishra, 2002; El-Ostra et al., 2004; Goodwin and Mishra, 2005; Girante et al., 2008; Key and Roberts, 2009; O'Donoghue and Whitaker,2010; Weber and Key, 2012), and (iii) by estimating elasticity of production and input use with respect to decoupled subsidies using structural equation models (Serra et al., 2005; Serra et al., 2006; Serra et al., 2011). In the dynamic context, the impact of decoupled subsidies on output, producer's input use decisions and investment decisions, is investigated using dynamic systems of structurally related equations (Coyle, 2005; Vercammen, 2007; Sckokai and Moro, 2009; Serra et al., 2009; Kallas et al., 2012).

2.3.2 Production decisions modelling using productivity and efficiency framework

Based on the fact that producers are not always successful optimisers, another stream of literature investigates the impact of subsidies on farm production through its effects on farm productivity and efficiency. In this stream of literature, subsidies are treated mainly as contextual drivers, that is as factors which are neither input nor output but that form part of the backdrop of production decisions. Nonetheless, given the absence of clear theoretical guidance on how to model contextual drivers, some empirical studies model the effects of subsidies in an ad hoc fashion (McCloud and Kumbhakar, 2008). The most commonly used frameworks in the existing empirical literature include the parametric Stochastic Frontier Approach (SFA) and the nonparametric two-stage Data Envelopment Analysis (DEA).

In the SFA framework the relationship between public subsidies and efficiency is examined by estimating a frontier of best production practices while assuming that deviations from this frontier may not be entirely under the control of the decision-makers. This approach supposes the existence of a convoluted error term which can be split into an idiosyncratic error and non-negative error reflecting technical inefficiency. In this framework, the impact of public subsidies on farm technical efficiency is estimated by specifying a likelihood function which accounts for the dependence of the inefficiency component on subsidies (Battese and Coelli, 1995). The potential drawback of this framework is that the estimation relies heavily on the choice of functional forms for the frontier as well as specific distributional assumptions for the inefficiency component (Kumbhakar et al., 2007). In the two-stage DEA approach, efficiency scores are estimated in the first stage without accounting for subsidy effects and then these scores are regressed on subsidies in the second stage. This approach is troublesome since it relies on a "separability assumption" which states that the input-output set is not influenced by subsidies (Daraio and Simar, 2007; Simar and Wilson, 2011). On this basis, it contrasts with theoretical studies which state that subsidies may influence the input-output space (see Hennessy, 1998; Serra et al., 2006). This implies that the two-stage DEA setting leads to the problem of omitting variables in the first stage, and thus in the second stage the disturbance terms are correlated with the regressors. To address this issue, the conditional efficiency framework (Daraio and Simar, 2007; Simar and Wilson, 2011; De Witte and Kortelainen, 2013) could be used.

Regarding the theoretical framework reviewed above and following Morroni (2006) who indicates that environmental conditions (contextual drivers) can be seen, among others, as individual capabilities, degree of uncertainty, equipment availability, institutional and market conditions, it follows that the conditional efficiency framework (Daraio and Simar, 2007; De Witte and Kortelainen, 2013) is a suitable setup for analysing the impact of decoupled payments on farm productive efficiency. The conditional efficiency framework is in line with expressions [2.5] and

[2.14], since it allows accounting for the influence of public subsidies on production decisions without treating them as input or as output. More specifically, this framework explicitly assumes that public subsidies may influence the choice and the level of input use (Minviel and De Witte, 2015a).

To account for the fact that subsidies may influence the input-output space, alternative modelling frameworks treat subsidies as input (e.g. Kroupová and Malý, 2010; Malá et al., 2010; Trnková et al., 2012) or as output (e.g. Rasmussen, 2010; Silva and Marote, 2013). In some papers that treat subsidies as output there is no explicit justification (e.g., Silva et al., 2004; Hadley, 2006). However, in Rasmussen (2011) there are the following arguments : "If a farmer buys one hectare of land with the sole purpose of generating subsidy in the form of single payment, these subsidies have to be considered as a product (an output) in line with other products like grain, meat or milk. The reason is that if we consider an additional hectare of land without any change in production, then we will say that productivity decreases. This result is wrong from the point of view of the farmer, because for him the additional hectare of land generates outputs in the form of subsidy". If this argument is true, only a part of the subsidies should be considered as output. Another argument is that the subsidies are used as proxy for non-market output produced by farms (e.g. Jan et al., 2012 ; Mamardashvili and Schmid, 2013). Another justification used for modelling subsidies as output is that they are like additional incomes for farmers (e.g. Soares et al., 2002 ; Banga, 2014). An economic argument against the modelling of subsidies as output is that they are not an output generated by the classic agricultural production technology. In papers where subsidies are modelled as inputs, it is argued that subsidies are used as explanatory drivers, in order to analyse their direct influence on output. Notice that this approach goes against the basic microeconomic theory of the producer, according to which the production function includes only inputs actually used in a technological process.

It must be stressed that from a methodological standpoint, treating subsidies as input or as output may create a modelling artefact. On the one hand, when subsidies are modelled as output they artificially inflate output production and tend to erroneously provide positive subsidy-efficiency nexus (Minviel and Latruffe, 2014). On the other hand, subsidies should not be modelled as input, since the theoretical framework reviewed above does not treat subsidies as input. Additionally, as stated by Ciaian and Swinnen (2009) and Latruffe and Minviel (2014), decoupled subsidies are generally used to purchase parts of conventional inputs (land, labour, capital, intermediate inputs) included in the efficiency model. Thus modelling subsidies as input results in double counting.

Another approach, which could be linked to expression [2.6], is the framework proposed by Sipiläinen and Kumbhakar (2008) and McCloud and Kumbhakar (2008). In this framework, subsidies are modelled as facilitating inputs, i.e., as factors that may alter marginal productivity of conventional inputs (e.g. labour, capital). The concept of facilitating input has been introduced by Guan et al. (2006) and is defined as factors " which help to create favourable growing conditions in preparing land, sowing and planting, applying fertilisers, harvesting". In a similar vein, Henderson and Parmeter (2015) employ the concept of "conditioning variables". The argument used to model subsidies as facilitating inputs is that "they may have technological effects. In fact, they could influence the actual production technology by affecting the response rates and the shapes of isoquants. For example, input specific productivity may decrease or increase if the input is used less or more effectively. Consequently, they influence indirectly the output by changing the marginal productivity of inputs (as they influence their use)". As in the case of estimating a complete system of structural equations, treating decoupled subsidies as facilitating inputs allows modelling producers' behaviour as well as the technology available to them. In this view and regarding expressions [2.5] and [2.14], not only subsidies but also prices should be treated as facilitating inputs. Except for Bokusheva et al. (2012) and Minviel and De Witte (2015b), the approach treating subsidies as facilitating inputs has not been followed in the literature. One possible reason may be that it departs from the basic microeconomic production theory. Indeed, we learned from basic microeconomics that output is only function of inputs.

In line with expression [2.17] and based on the fact that producers are not always successful optimisers, another promising avenue is to examine the impact of decoupled subsidies on productive efficiency using a stochastic dynamic framework. As previously stated, a stochastic dynamic framework may allow accounting for intertemporal production decisions.

As mentioned above, another stream of literature investigates the impact of decoupled subsidies on production activity through its impact on the total factor productivity (TFP). To do so, two mainstream approaches are used. The first approach uses a two-step procedure, which consists in estimating the TFP in the first step using DEA, SFA, or the Olley and Pakes (1996) production setup without accounting for subsidy effects, and then the estimated TFP is regressed on decoupled subsidies and other potential determinants (Guan and Oude Lansink, 2006; Kazukauskas et al., 2010; Mary, 2013). This two-step procedure is potentially biased due to omitted variable issue in the first step. The second approach is a modified version of the Olley and Pakes (1996) productivity framework, which explicitly accounts for subsidy effects in the first step, then in the second step a simple correlation analysis is sufficient (see Rizov et al., 2013). Likewise, a modified version of the Levinsohn and Petrin (2003) production setting can be used (see Kazukauskas et al., 2014). Similarly, the framework of Wooldridge (2009) can also be modified to examine the impact of decoupled payments on farm aggregated productivity. Importantly, the framework proposed by Wooldridge (2009) is built upon shortcomings of the

Olley-Pakes and Levinsohn-Petrin framework (see Ackerberg et al., 2006; Ackerberg et al., 2007).

Productivity is often estimated as Solow's (1957) residual, i.e., as the gap between observed output and output predicted by ordinary least squares estimation of a Cobb-Douglas production function. By so doing, a simultaneity issue arises because of potential correlations between input quantities and productivity shocks which are observable or predictable by farmers but not by econometricians. In fact, farmers could respond to positive productivity shocks (e.g. high quality of land or expected rainfall) by using more inputs to expand their outputs. Likewise, they could respond to negative productivity shocks by using less inputs. Olley and Pakes (1996) introduce an estimator that uses investments as proxies for unobservable productivity shocks. More precisely, they assumed that demand for investments is a strictly increasing function of the productivity shocks and capital stock; in turn, they suggest to invert this function to express the productivity shocks as an unknown function of investments and capital. The Olley-Pakes estimator is a two-step procedure where coefficients for variable inputs are estimated in the first step, and the coefficient on capital is estimated in the second step. Levinsohn and Petrin (2003) propose a modified version of the Olley-Pakes estimator, that uses intermediate inputs as proxies, to circumvent the issue of discontinuous investments. However, Ackerberg et al. (2006) and Ackerberg et al. (2007) show that variable inputs (such as labour) are also function of the productivity shocks. Consequently, their underlying parameters cannot be correctly identified because of collinearity issues. In addition, Wooldridge (2009) argue that the two-step estimators are inefficient for two reasons: (i) they do not account for correlations in the errors across equations, and (ii) they do not efficiently account for serial correlation and heteroskedasticity in the errors. To address theses issues, Wooldridge (2009) propose a GMM (generalised method of moments) single step estimator.

2.3.3 Decoupled payments and productive efficiency under risk and uncertainty

In the empirical literature two main frameworks are available for analysing productive efficiency under risk and uncertainty. The first one is an extension of the Just-Pope production risk model to account for technical efficiency and producers' attitude toward risk (Battese et al., 1997; Kumbhakar, 2002). The second framework relies on the state-contingent production theory (Chambers and Quiggin, 2000; O'Donnell et al., 2010; Nauges et al., 2011; Chambers et al., 2015).

Battese et al. (1997) and Kumbhakar (2002) extend the Just-Pope production function for integrating technical efficiency. However, the extension suggested by Kumbhakar (2002) is more flexible since it allows explaining technical efficiency. The formulation of Kumbhakar (2002) can be expressed as follows:

$$y = f(x;\beta) + g(x;\alpha)\nu - h(z;\gamma)u \tag{2.18}$$

where y is the observed output quantities; x is a vector of inputs; $f(.)$ is the mean production function (frontier); $g(.)$ denotes the output variability function; $\nu \sim N(0,1)$ is a homoskedastic error term representing production uncertainty; $u \sim N^{+}(\mu, \sigma_u^2)$ is a non-negative error term capturing technical inefficiency; $h(.)$ is a scaling function for u; and β, α and γ are unknown parameters to be estimated. The mean function $f(.)$ describes the maximal attainable production for a given input level, the variance function $g(.)$ captures the relationship between inputs and output variability, and the scaling function incorporates technical inefficiency determinants. The variable z stands for decoupled payments as well as other contextual drivers. More importantly, expression [2.18] can be very useful for capturing complementarity and substitutability between input use and subsidies if the input vector x is included into $h(.)$. The functions $f(.)$, $g(.)$, and $h(.)$ can be estimated simultaneously by maximising the log-likelihood function of expression [2.18]. Interestingly, expression [2.18] is equivalent to the well-known heteroskedastic stochastic frontier (Wang, 2002; Jaenicke et al., 2003; Hadri et al., 2003).

In contrast to the traditional stochastic representation of production technologies in which uncertainty is confounded with statistical noises (O'Donnell et al., 2010), the state-contingent production theory explicitly models uncertain production conditions through a set of states of nature. In the context of efficiency measurement, this may facilitate differentiating inefficiency from effects due to heterogeneous production environments (Chambers et al., 2015). In this line, following Chambers et al. (2015), De Witte and Kortelainen (2013) and Daraio et al. (2007), one can subsume the state-contingent approach and the robust conditional efficiency setting to investigate the subsidy-efficiency nexus. In addition, under the state-contingent production theory, the impact of decoupled payments on farm's productive efficiency can be investigated using a nonparametric structural setting. That is, one can estimate the stochastic production frontier using nonparametric instrumental variables (NPIV) method by allowing for a normal-half normal convoluted error term and by using subsidies as instrument and as determinant of technical inefficiency.

2.4 Concluding remarks

In the jargon of the World Trade Organization (WTO), decoupled payments have been conceptualised as green-box subsidies, i.e., as government payments that are production neutral and thus preclude trade distortion of agricultural markets. From basic microeconomic theory, farmers' decisions about what and how to produce depend on the returns and the costs of producing additional units (marginal returns and marginal costs). On this basis, although decoupled subsidies raise farm total revenues, they could not influence farmers' production decisions since they do not change per-unit net returns of production. However, based on advanced theoretical reasoning, various mechanisms through which decoupled subsidies may impact production decisions have been identified. This chapter reviews these mechanisms. It underlines that decoupled subsidies are production neutral only if producers do not face binding credit constraints and/or are risk neutral. In fact, the review shows that the main mechanisms through which decoupled subsidies could impact production decisions include a wealth and an insurance effect which may involve (i) risk-related effects when farmers have non-neutral risk preferences and face uncertainty related to output and/or prices, (ii) static effects under liquidity constraints, (iii) dynamics effect related to investment decisions, and (iv) effects related to labour decisions (allocation of family labour to off-farm activities).

Empirically, these effects could be analysed using partial and general equilibrium models, mathematical programming methods, and econometric techniques. However, methodologically, the econometric approaches seem to be suitable given their ability to account for incentive effects generated by decoupled payments at farm-level. Hence, if farmers are assumed to operate under the first-order conditions (FOCs), the impact of decoupled payments on their production decisions can be analysed by jointly estimating a system of structurally related equations of decisions (output supply and input use). In the same vein, using standard regression techniques, decoupled payments can be related to crop acreage decisions, land acquisition, and farmers' labour-leisure decisions. These investigations can be done in static as well as in dynamic frameworks.

However, relaxing the assumption that all producers operate under the FOCs, the influence of decoupled payments on production activities can be examined using structural productivity models, parametric productive efficiency models, and conditional efficiency models. To account for risk and uncertainty, these models could be estimated under the state-contingent production framework, or using an extension of the Just-Pope production risk model. Overall, it must be stressed that analytical approaches that do not have sound theoretical grounds (e.g. modelling subsidies as inputs or as outputs) may generate misleading results.

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Chapter 3

Effect of public subsidies on farm technical efficiency: A meta-analysis of empirical results[1]

Abstract

Predicting and investigating the impact of public subsidies on farm technical efficiency are becoming critical issues in applied agricultural policy analysis. This chapter presents a meta-analysis of empirical results on this issue, based on data gathered from a systematic literature review. We find that, in the empirical literature, subsidies are commonly negatively associated with farm technical efficiency. Meta-regression estimation results show that the direction (significantly negative, significantly positive or non-significant) of the observed effects is sensitive to the way subsidies are modelled in the empirical studies, and to the period of publication.

3.1 Introduction

Given successive reforms of agricultural policies and pressures on public budgets, investigating the link between public subsidies and farm technical efficiency has become a central research question in production economics. Technical efficiency refers to the capacity of a farm to make efficient use of the existing technology, that is, either to produce at the maximum level with a given set and level of inputs, or to use the minimum level of inputs to produce a specific level of output. In general, public subsidies do not aim explicitly at improving technical efficiency, but instead aim at increasing production, supporting farmers' income, or favouring the production

[1]This chapter has been written in collaboration with Laure Latruffe (INRA, UMR SMART, Rennes, France).

of specific outputs including environmental outputs. However, if subsidies have the side effect of decreasing farm technical efficiency, this may lead to the question of whether a more effective way of supporting farms might exist.

Theoretical results on this subsidy-efficiency link are ambiguous. On the one hand, subsidies may reduce farmers' effort (Martin and Page, 1983) or change their risk attitudes (Serra et al., 2008), which might result in a reduction of technical efficiency. More generally, a negative impact of subsidization on technical efficiency may result from a wealth (income) effect, that is to say, income stabilisation resulting from subsidies may distort farmers' incentives to produce efficiently. Farmers' efforts in farming activities may be reduced if a larger part of their income is guaranteed by subsidization. Subsidization may enable farmers to smooth their wealth without adopting efficient production strategies. On the other hand, subsidies may help farmers overcome financial constraints that impede efficient restructuring or modernisation, and thus may increase technical efficiency by improving the farm's productive capacity through replacement investment or net investment in advanced technologies (Zhu and Oude Lansink, 2010). Also, one may expect no significant effect (that is, null effect) of subsidies on technical efficiency, since this is not the primary aim of the subsidization policy. Consequently, several authors, such as Serra et al. (2008), Kumbhakar and Lien (2010) and Zhu and Oude Lansink (2010), argue that investigating this issue is essentially empirical. However, findings from empirical studies also seem inconclusive. Significant effects, both positive and negative, of subsidies on farm technical efficiency may be found, along with no significant effects. The empirical studies differ not only in the context of the study (for example: country, period, types of farm considered), but also in the data used (for example: number of farms, cross-sectional or panel data) and in the methodology employed (for example: a parametric or non-parametric approach). Hence, one may wonder whether the direction of the subsidy-efficiency relationship found in the empirical literature is random, or whether it is consistently related to the characteristics of the studies.

In this context, this chapter aims to shed light on the relationship between public subsidies and farm technical efficiency by undertaking a meta-analysis of results obtained in existing empirical studies. The meta-analytical framework consists of a set of statistical and econometric methods which allows outcomes from empirical studies carried out on a particular research question to be synthesised and their heterogeneity to be investigated (Glass, 1976; Stanley and Jarell, 1989). If there is a consistent link between the direction of the relationship found in the studies and certain characteristics of the studies, this may help draw methodological recommendations, so that future research provides reliable findings for policy recommendations.

The chapter is organised as follows. In Section 3.2, we present an overview of the possible ways of investigating the relationship between farm technical efficiency and subsidies which have been applied in the existing empirical literature. In Sections 3.3 and 3.4, we present the data and methodology, respectively. In Section 3.5 we describe and discuss the main results. Section 3.6 concludes.

3.2 Overview of the ways of estimating the link between farm technical efficiency and subsidies

Various estimation strategies can be found in the literature dealing with the efficiency-subsidy link. There are two main competing approaches: the non-parametric framework where the main method is Data Envelopment Analysis (DEA); and the Stochastic Frontier Analysis (SFA) which is a parametric framework. Both approaches allow farm specific efficiency scores to be computed. These are strictly positive scalars bounded by one, with one being a fully efficient farm.

DEA relies on programming methods to construct a linear frontier from the best performing farms in the sample at hand. The DEA model may have an output orientation meaning that it is searched for the possible output increase that farmers could implement without changing the level of use of inputs. Researchers may prefer to assume an input orientation, where the possible input decrease – keeping output the same – is searched for. The main advantages of DEA are that it can handle a multi-output multi-input context, and it does not necessitate specification assumptions. In DEA, the influence of subsidies is investigated in two stages: in the first stage, technical efficiency is computed with DEA; and in the second stage a regression (Ordinary Least Squares, truncated, Tobit, or quantile) is applied to the efficiency scores.

In contrast to DEA, SFA relies on econometrics and therefore necessitates specifications regarding the production function and the distribution of error terms. However, one advantage of SFA is that it accounts for potential noise through its double error term (random noise and inefficiency), while in the DEA case any deviation from the efficient frontier is due to inefficiency. Bayesian methods can be used to provide more accurate inference results, for example accounting for regularity conditions. In the SFA case, the computation of efficiency and the effect of subsidies on efficiency are estimated in a single stage. More information on efficiency estimation can be found in Coelli et al. (2005).

A further approach for investigating the efficiency-subsidy link relies on simple correlation analysis or on comparing the means of different sub-samples on the basis of the farms' efficiency scores calculated with either DEA or SFA.

As mentioned above, different types of data may be used. One possibility is to use cross-sectional data, where farms are observed in one specific year. Panel data can also be used, where the same farms are observed in adjacent years. Some studies investigate the relationship between farm technical efficiency and subsidies in a specific year only, while other studies consider longer periods which, in some instances, enable any change in the way subsidies are allocated to farms to be captured. Although various levels of observations can be found in the efficiency literature, only studies using individual data, that is to say farm level data, are found in the literature dealing with the subsidy-efficiency issue.

Regarding subsidies, the subsidization policy depends on the context of the study. However, in general one can observe that the total value of subsidies received by farms can be decomposed into several components, such as subsidies for implementing investment on the farm, or subsidies for production activities. The latter can be disaggregated into several types, such as input subsidies, output subsidies or coupled subsidies (that is, subsidies coupled with production), decoupled subsidies (that is, lump-sum payments), environmental subsidies (that is, subsidies favouring environmentally-friendly practices such as organic farming), and subsidies provided to farms located in difficult situations. An example of the latter is from the Common Agricultural Policy (CAP) of the European Union (EU) where farms located in the so-called Less Favoured Areas (LFA) receive specific subsidies per hectare of area in LFA. Regarding coupled and decoupled subsidies, and taking again the example of the EU, over the past decades the CAP has gradually moved from coupled subsidies to decoupled subsidies. In the mid-1990s, partially decoupled payments were introduced in the form of direct payments received per hectare of specific crop planted or per head of specific livestock bred. More recently, the decoupled Single Farm Payment has been implemented.

When investigating the relationship between farm technical efficiency and subsidies, the subsidies considered may be given as the total value received by the farm. However, this might capture size effects. Some studies circumvent this issue by relating the subsidies considered to a size variable (such as the value of farm revenue, or the farm area in hectares, or the number of farm livestock units), or by calculating them as a share of all subsidies received by farms. A final point to note regarding the methodologies used in the empirical literature on the subsidy-efficiency link relates to the way in which subsidies are modelled. In general, subsidies are used as contextual factors, that is to say as explanatory variables to efficiency. Subsidies may also be considered as an additional output to the traditional farm outputs used in the efficiency calculation. This is not, however, a correct method for accounting for subsidies, since it implies that, for a similar input use, farms receiving subsidies produce more in value than farms not receiving subsidies. Such an approach does not reflect the real production process of farms.

3.3 Data

The data used in our meta-analysis consist of 195 observations (that is, 195 distinct results about the effect of subsidies) extracted from a set of 68 studies which were carried out during the period 1986 to 2014. The studies were collected from a systematic review of the existing empirical literature on the links between public subsidies and farm technical efficiency. The search for papers was conducted through the main scientific databases such as Econlit, Web of Science (WoS), Web of Knowledge (WoK), JSTOR, Econpapers, Science Direct, RepEc (IDEAS) and Google Scholar, combining in several search formulae the following keywords: 'subsidies' or 'support', alone or with 'public', 'government', 'CAP', 'Single Farm Payment', 'pillar 1', 'pillar 2', 'agricultural', 'EU', or 'farm bill'; together with 'efficiency', technical efficiency', 'economic efficiency', 'farm efficiency', 'productive efficiency', 'farm performance' or 'economic performance'. The literature search was completed by exploring the reference lists of the papers obtained through the search of the databases. One important potential bias in meta-analyses is publication bias, which refers to the fact that studies that are more likely to be submitted and published in journals, as well as those cited, are those where results are significant and interesting (Coursol and Wagner, 1986; Hedges, 1992; Begg, 1994; Sterne et al., 2000; Dickersin, 2005). In addition, it has been documented that certain studies remain unpublished because of theoretical or ideological divergences, or conflicts of interest between researchers (Sterling, 1959; Mahoney, 1977). On the one hand, it may be viewed as a quality guarantee that studies which do not comply with theoretical beliefs are not published in recognised journals. On the other hand, at least in this array of literature, theory is not frozen, as can be seen from recent suggestions of a possible positive relationship between subsidies and farms' technical efficiency (e.g. Zhu and Oude Lansink, 2010; Kumbhakar and Lien, 2010). Therefore, meta-analyses based only on literature published in journals may be biased. Given this, and as recommended (e.g. Cook et al., 1993; MacLean et al., 2003; Rothstein et al., 2005; Sterne et al., 2008), we introduce some unpublished studies in our meta-analysis.

Table 3.4 (in the appendix at the end of this chapter) provides an overview of the empirical studies on the relationship between public subsidies and farm technical efficiency. Various points should be noted. The first concerns the geographical coverage: developing and emerging countries are not widely covered by the existing literature. Only India (Charyulu and Biswas, 2010; Dung et al., 2011), China (Thian and Wan, 2000; Li et al., 2012) and Brazil (Taylor et al., 1986) have been the focus of such an assessment. Within industrialised countries, it is worth noting that the majority of studies cover Europe. Despite some of the earliest studies being on Canada (Giannakas et al., 2001) and the United States (Lachaal, 1994), there are only four more studies on the United States (Lambert and Bayda, 2005; Serra et al., 2008; Chidmi et al., 2011; Zaeske, 2012). In Europe, one publication has focused on Switzerland

(Ferjani, 2008), two on Norway (Kumbhakar and Lien, 2010; Kumbhakar et al., 2012) and two on Russia (Sotnikov, 1998; Sedik et al., 2000). The EU appears to be largely covered but it is not covered in terms of the variety of authors. In fact, some authors have applied their model to several EU countries in a single publication (Latruffe et al., 2008; McCloud and Kumbhakar, 2008; Fogarasi and Latruffe, 2009; Zhu and Oude Lansink, 2010; Latruffe et al., 2012; Zhu et al., 2012) or to several production sectors in the same country (Karagiannis and Sarris, 2002; Guyomard et al., 2006; Hadley, 2006; Kleinhanss et al., 2007; Emvalomatis et al., 2008; Caroll et al., 2009; Fogarasi and Latruffe, 2009; Desjeux and Latruffe, 2010).

A second point concerns the production coverage. Most of the studies concentrate on the crop and dairy sectors, followed by beef cattle, sheep and pig. Some studies cover specific crops (cereals, oilseeds and protein-seeds (COP), cereals, wheat, corn, rice, alfalfa, tobacco, cotton, olive, fruits, vegetables, horticulture) and one study is applied to poultry. Crop production other than field crops is studied in countries with specific production conditions (rice in China; olives in Greece and Spain; alfalfa, tobacco, cotton in Greece).

A third point concerns the period covered. When looking at the dates of publications, the pioneer papers are by Taylor et al. (1986) for Brazil, Lachaal (1994) for the United States and Sotnikov (1998) for Russia, who explicitly focused on the effect of public support (credit subsidization, farm subsidies, output subsidies, respectively) on technical efficiency. A few papers followed in the early 2000s, namely Brümmer and Loy (2000), Sedik et al. (2000), Giannakas et al. (2001), and Karagiannis and Sarris (2002), but most of the assessment started in the mid-2000s, and has increased in the past ten years. Papers have mostly covered periods ranging from the early 1990s to the most recent data available in the 2010s. This corresponds to a period when micro-economic data became more widely available, and when decision-makers increased their demand for policy evaluations.

A final point concerns the subsidy variables used. Various variables are used in the literature, dealing with total subsidies received by farms, or specific subsidies such as production subsidies, investment subsidies, environmental subsidies, organic subsidies, or output subsidies (that is, subsidies coupled to output). The subsidies are proxied with either: the total amount per farm; the average amount per hectare of land or livestock head; a so-called subsidy rate, which is a ratio relating the subsidies considered to a farm financial performance indicator (output value, revenue, income); or a ratio of the subsidies considered to the total subsidies received by the farm (the payment ratio). Alternatively, a dummy is used to capture whether the farm was the beneficiary of subsidies or whether there has been a change in policy.

The last column of table 3.4 shows that the most common finding on this issue is an inverse relationship. When non-significant relationships are not considered, the effect of subsidies on technical efficiency is significantly negative for 71% of the models, and significantly positive for 29%. When taking into account the cases where subsidies have no significant effect, which is also a result in itself, then the effect is significantly negative for 60% of the models, significantly positive for 24% of the models, and non-significant for 16%. At first sight, there is no obvious consistency in the results. For example, contradictory results are found for a given production sector with a similar subsidy variable (e.g. Hadley, 2006, and Iraizoz et al., 2005, for the beef production sector). Also, among studies in which the subsidy rate is, on average, similar, a significantly positive impact and a significantly negative impact of support on technical efficiency can be found; contrast Kumbhakar and Lien (2010) and Kumbhakar et al. (2012), both for Norwegian cereal farms but using a different proxy for subsidies. Table 3.1 provides additional statistics regarding the estimated impact for the studies listed in table 3.4. Table 3.1 shows that, among studies considering total subsidies (instead of various categories of subsidies), the share of observations reporting a significantly negative effect of subsidies on technical efficiency is higher than the share reporting a significantly positive or a non-significant effect. The same finding is observed among studies modelling subsidies as a subsidy ratio per farm income.

Table 3.1 Share of observations depending on the sign of the estimated effect

	Share of the 195 observations (%) reporting		
	Significantly negative estimated effect	Null (non-significant) estimated effect	Significantly positive estimated effect
All 195 observations	54	22	24
Depending on:			
The type of subsidies used			
Total subsidies	29	6	7
Input subsidies	2	1	1
Environmental subsidies	6	3	4
LFA subsidies	4	2	1
Investment subsidies	1	2	4
Coupled subsidies	8	2	4
Decoupled subsidies (including direct payments and Single Farm Payment)	46	20	20
The subsidy proxy used			
Value of subsidies per farm	10	8	11
Subsidy rate	35	4	2
Subsidies per hectare	5	2	5
Subsidies per animal			
Subsidy dummy	4	8	6
The type of farms considered			
Crop farms	21	9	7
Dairy farms	18	7	12
Other livestock farms	7	6	6

Notes: The estimated effect refers to the effect of subsidies on technical efficiency found in the primary studies.

3.4 Empirical models

We explore here econometrically the heterogeneity of the direction of the subsidy effect in empirical studies by using categorical models. More precisely, we use probit models to investigate the determinants of the sign of the coefficient associated with the subsidy variable. Firstly, we consider the three possible directions by estimating an ordered probit model with three categories ordered as follows: the first outcome of the ordinal dependent variable is a significantly negative effect; the second outcome is a null (that is to say, non-significant) effect; and the third outcome is a significantly positive effect. The dependent variable y_i for the i-th study thus takes the value j=1, 2 or 3, and is associated with an underlying latent variable[2] y_i^*, such that:

$$\begin{aligned} y_i^* &= \beta x_i + \xi_i \\ y_i &= \begin{cases} 1 \ if \ y_i^* < \delta_1 \\ 2 \ if \ \delta_1 < y_i^* < \delta_2 \\ 3 \ if \ y_i^* > \delta_2 \end{cases} \end{aligned} \tag{3.1}$$

where x_i is a $1{\times}p$ vector of moderator variables explaining the observed effects; β are the parameters to be estimated; and ξ_i is a standard normal shock. δ_1 and δ_2 are the cutpoints or threshold parameters to be estimated from the data. They help to match the latent variable to the observed variable, and to estimate the probability associated with each observed effect. Given the moderator variables, the probability that $y_i = j| \ j \in (1, 2, 3)$ is given by:

$$\begin{aligned} Prob\,(y_i = 1) &= \phi\,(\delta_1 - \beta x_i) \\ Prob\,(y_i = 2) &= \phi\,(\delta_2 - \beta x_i) - \phi\,(\delta_1 - \beta x_i) \\ Prob\,(y_i = 3) &= 1 - \phi\,(\delta_2 - \beta x_i) \end{aligned} \tag{3.2}$$

where $\phi\,(.)$ stands for the cumulative probability function of the standard normal distribution. While the signs of the estimated parameters β can give an indication of whether the latent variable y_i^* increases from outcomes 1 to 3 when the determinant increases (or when the determinant takes the value one in the case of a dummy variable), marginal effects can help compare the effect of the determinants. More precisely, marginal effects, calculated for each determinant and each alternative k, show the percentage increase in the probability of the alternative k when the determinant increases by one unit (or takes the value one in the case of a dummy variable).

Secondly, since the ordering of the outcomes is not a natural one (although it is logical to order from a negative to a positive outcome), we also estimate binary probit models to confirm or disconfirm findings obtained with the ordered probit model. In the first binary probit model that we estimate, we assume that only significantly negative effects of subsidies on farms' technical efficiency are not considered desirable by policy-makers, and thus we group

[2]This variable does not have the traditional meaning of latent variables (as in biology or behavioural studies). Here, it only allows modelling the probability of observing a positive, negative, or null effect, conditionally to the moderator variables.

significantly positive effects and null effects together. Hence, the binary dependent variable is equal to one for significantly positive or null effects, and equal to zero for (undesirable) significantly negative effects (reference category). Finally, for comparison purposes, we also estimate a binary probit model in which the dependent variable is equal to one for significantly positive effects, and equal to zero for significantly negative effects (reference category). The full sample of 195 observations is here reduced to 153 observations (the observations with non-significant effects are excluded). The probability of obtaining the considered outcome with respect to the reference outcome is given by:

$$Prob\left(y_i = 1|x_i, \beta\right) = \int_{-\infty}^{-x_i\beta} \phi\left(z\right)dz \tag{3.3}$$

where $\phi\left(z\right)$ denotes the standard normal density.

For a given empirical study, the estimated models are assumed to be independent if they consist of estimations for different countries, different regions, or different farming systems. However, in the estimation procedure, to control for intra-study auto-correlation due to the fact that multiple observations are drawn from a given paper, we use cluster-robust inference. In this approach, which has been used in meta-regressions (see Barrio and Loureiro, 2010; Choumert et al., 2013), the standard errors are clustered by each primary study.

As explained above, we investigate whether the direction of the effect depends on the characteristics of the primary study such as the analytical method employed to investigate the impact and the context of the study. More precisely, the following explanatory variables x_i are used in our three probit models: (i) One dummy captures the way subsidies are modelled: subsidies as additional output in the efficiency calculation (Subsidies as output). (ii) The type of subsidy considered in the primary study is included via eight dummies: Total subsidies, Input subsidies, Environmental subsidies, LFA subsidies, Investment subsidies, Coupled subsidies, Direct payments, and Single Farm Payment. (iii) Two dummies are included to capture which proxy of the subsidies is used, namely Subsidy per revenue and Subsidy per hectare. (iv) The influence of the estimation strategy followed in the primary studies is tested through five dummies: Parametric estimation, that is to say SFA; one dummy representing whether Bayesian techniques have been used for SFA estimation (Bayesian estimator); two dummies for the way the efficiency score calculated with DEA in the first stage is explained (Quantile regression; Tobit regression); and whether the output-orientation (as opposed to input-orientation) is assumed for the calculation of technical efficiency with DEA (DEA output-orientation). (v) The type of data used is considered through the dummy Panel data. (vi) The geopolitical location of the farms considered in the primary study is included in the meta-regression since it is expected that policy incentives and room for manoeuvre may differ depending on the farm location. This is done via the dummy EU-area equal to one for studies on EU countries and zero otherwise, and the dummy North America equal to one for studies on North American countries and zero otherwise. (vii) The influence of the publication period and of the publication status on the direction of the subsidy effect is investigated through two dummies: Publication period and Publication status. The former takes the value one for papers published in 2003 or before. This dummy is aimed at capturing scientific progress in the technical efficiency literature, and investigates the potential effect on findings regarding the efficiency-subsidy relationship. The latter dummy captures whether the studies are articles published in academic journals.

As mentioned above, we believe that modelling subsidies as an additional output in the production process is not correct. For this reason, all three models (the ordered probit and the two binary probit models) are also estimated excluding the observations relying on such a modelling approach, thus reducing the full sample of 195 observations to a sub-sample of 150 observations (and in the case of the second probit model where observations reporting non-significant effects are excluded, the sample is reduced from 153 to 122 observations). The definition and descriptive statistics for the moderator variables for both the full sample and the sub-sample are presented in Table 3.2. It can be noted that there is a large array of the types of subsidy considered but most of the models used total subsidies (44%). Regarding the modelling strategy, almost one quarter of the models (23%) include subsidies as additional output in the efficiency calculation, and most of the models (76%) use parametric estimation. Concerning the publication status, one half of the models are in journal publications (51%).

Table 3.2. Meta-analysis moderator variables and descriptive statistics

		Full sample		Sub-sample	
Variables	Description	Mean	SD	Mean	SD
Dependent variable					
Significantly negative	= 1 for significantly negative effect, 0 otherwise	0.54	0.49	0.62	0.49
Null (non-significant)	= 1 for null effect, 0 otherwise	0.22	0.41	0.18	0.39
Significantly positive	= 1 for significantly positive effect, 0 otherwise	0.24	0.43	0.2	0.40
Significantly positive or null	= 1 for significantly positive or null effect, 0 otherwise	0.46	0.49	0.38	0.49
Moderator variables					
Subsidies as output	= 1 if subsidies are modelled as output, 0 otherwise	0.23	0.42	0	
Total subsidies	= 1 for total subsidies, 0 otherwise	0.44	0.49	0.46	0.50
Input subsidies	= 1 for input subsidies, 0 otherwise	0.04	0.18	0.05	0.21
Environmental subsidies	= 1 for environmental subsidies, 0 otherwise	0.12	0.33	0.09	0.29
LFA subsidies	= 1 for LFA subsidies, 0 otherwise	0.05	0.22	0.03	0.18
Investment subsidies	= 1 for investment subsidies, 0 otherwise	0.06	0.24	0.07	0.26
Coupled subsidies	= 1 for coupled subsidies, 0 otherwise	0.13	0.34	0.14	0.35
Direct payments	= 1 for direct payments, 0 otherwise	0.8	0.40	0.83	0.38
Single Farm Payment	= 1 for Single Farm Payment, 0 otherwise	0.11	0.32	0.12	0.33
Subsidies per revenue	= 1 for the amount of subsidies per revenue, 0 otherwise	0.41	0.49	0.41	0.49
Subsidies per hectare	= 1 for the amount of subsidies per hectare of land, 0 otherwise	0.11	0.32	0.13	0.33
Parametric estimation	= 1 for parametric estimation in the case of SFA, 0 otherwise	0.76	0.43	0.75	0.43
Bayesian estimator	= 1 for Bayesian estimation in the case of SFA, 0 otherwise	0.05	0.21	0.06	0.24
Quantile regression	= 1 for quantile estimation in the second stage following DEA, 0 otherwise	0.03	0.16	0.03	0.18
Tobit regression	= 1 for Tobit estimation in the second stage following DEA, 0 otherwise	0.06	0.24	0.08	0.27
DEA output-orientation	=1 for DEA output-oriented model, 0 otherwise	0.11	0.31	0.13	0.33
Panel data	= 1 for panel data, 0 otherwise	0.87	0.33	0.92	0.29
EU area	= 1 for EU member states, 0 otherwise	0.82	0.38	0.78	0.41
North America	= 1 for North American countries, 0 otherwise	0.03	0.17	0.04	0.19
Publication period	=1 for papers published in 2003 or before, 0 otherwise	0.11	0.31	0.13	0.34
Publication status	= 1 for articles published in journals, 0 otherwise	0.51	0.50	0.48	0.50
Number of observations		195		150	

Notes: SD= Standard deviation

3.5 Results and discussion

Estimation results for the ordered probit model and for the two binary probit models for the full sample are presented in Table 3.3. The results for the models for the sub-sample excluding observations modelling subsidies as output are not shown. The likelihood ratio and R-squared statistics in Table 3.3 indicate that all three models have a high goodness-of-fit. In addition, the percentages of correctly predicted observations for the two binary probit estimations suggest that both models are well behaved. However, in the estimation of the ordered probit model, the second threshold parameter (Cut2) is not statistically significant, suggesting that the second and the third categories (namely non-significant and significantly positive effects) could be collapsed into one single category, as in the case of our first probit model. In the estimation of the ordered probit model in the sample excluding observations treating subsidies as output, none of threshold parameters is statistically significant, suggesting that the ordered structure is not appropriate.

The estimates of the meta-regression analysis for the full sample in Table 3.3 highlight several main findings[3] from the empirical literature on the relationship between public subsidies and farms' technical efficiency. Firstly, when subsidies are modelled as an additional output in the calculation of technical efficiency, the probability of obtaining a significantly negative effect of subsidies on technical efficiency decreases, and the probability of obtaining a significantly positive effect increases. The intuition is that modelling subsidies as output tends to virtually inflate the output value, while there is no associated increase in input use. Hence, farms with larger subsidies are considered to be producing more output with the same level of inputs. As explained above, this approach is not a correct way of modelling a production process. This meta-regression finding may explain some of the contrasting findings reported in the literature. For instance, using the classical SFA framework and modelling subsidies as output, Hadley (2006) found a significantly positive impact of subsidies on technical efficiency for beef farms in England and Wales, while using the same framework but considering subsidies as contextual variables only, Iraizoz et al. (2005) found a significantly negative impact for Spanish beef farms. Another example is the contrasting results reported by Areal et al. (2012) and Mamardashvili and Schmid (2013) for environmental subsidies and dairy farms.

Secondly, aggregating all subsidies received by farmers into a total subsidy variable may hide effects attributed to specific subsidies, while modelling each type of subsidy separately appears to be an appealing way to isolate their effect. For example, results regarding the ordered

[3]Notice that many variables are non-significant. This suggests that the direction of the effect is not systematically influenced by these variables. In fact, we have estimated the models by permuting the variables using the method of "ClustOfVar" (a method which allows grouping together variables which are strongly related or variables which bring the same information) (Chavent et al., 2012), but their significance remains unchanged.

probit in Table 3.3 show that in the literature, total subsidies are ambiguously related, in a non-significant or significantly negative or positive, way to farms' technical efficiency, while investment subsidies and coupled subsidies are significantly positively related to farms' technical efficiency. However, this finding is not confirmed by the two binary probit models. What is shown by all three models (ordered and binary probit models) in Table 3.3 is that using the proxy of subsidies per revenue decreases the probability of obtaining a significantly positive or non-significant effect on farm's technical efficiency. This finding is also confirmed by both binary probit models run for the sub-samples excluding observations considering subsidies as output.

Thirdly, the subsidy proxy used influences the result. More precisely, all models (whether for the full sample or the sub-samples excluding observations considering subsidies as output) consistently show that using the ratio of subsidies per farm revenue as the subsidy proxy, increases the probability of obtaining a significantly negative effect on farms' technical efficiency. This may be one of the reasons behind the discrepancy highlighted above regarding the findings by Kumbhakar and Lien (2010) and Kumbhakar et al. (2012) for Norwegian cereal farms. While the former found a significantly positive impact using the amount of subsidies received by the farm, the latter found a significantly negative impact using the subsidy rate.

Fourthly, in terms of methodologies, one finding is highlighted by the ordered probit model and the binary probit where significantly positive effects are compared to the reference of significantly negative effects in Table 3.3: using panel data increases the probability of obtaining a significantly negative effect of subsidies on farms' technical efficiency compared to using cross-sectional data.

Fifthly, results from all models for the full sample in Table 3.3 as well as results from binary probit models for the sub-sample excluding observations modelling subsidies as output, show a negative effect of the dummy regarding the publication period. This indicates that studies published in 2003 or before were more likely to obtain a significantly negative effect of subsidies on farms' technical efficiency than later studies.

Finally, an additional result highlighted by the estimates is that the variable EU area has a negative effect on the probability of obtaining a significantly positive effect (and on the probability of obtaining a non-significant effect) of subsidies on farms' technical efficiency. This suggests that studies applied to EU member states are more likely to report a negative effect of subsidies on farms' technical efficiency compared to other regions in the world.

Table 3.3 Ordered probit and binary probit estimates for the meta-regression

	Ordered probit	Ordered probit : Marginal effects			Binary probit	
	Estimates	Negative effect (j=1)	Null effect (j=2)	Positive effect (j=3)	Positive or null effect vs. negative effect	Positive effect vs. negative effect
Intercept					1.13 (0.79)	1.20 (1.46)
Subsidies as output	0.89 (0.30)***	-0.34 (0.11)***	0.09 (0.03)***	0.25 (0 .10) **	1.11 (0.30) ***	1.66 (0.52)***
Total subsidies	0.20 (0.36)	-0.08 (0.14)	0.03 (0.06)	0.04 (0. 08)	0.23 (0.41)	0.33 (0.62)
Input subsidies	0.49 (0.69)	-0.19 (0.26)	0.06 (0.04)	0.14 (0.23)	0.75 (0.74)	-1.23 (1.01)
Environmental subsidies	-0.44 (0.45)	0.16 (0.16)	-0.08 (0.08)	-0.08 (0.07)	-0.63 (0.44)	-0.42 (0.70)
LFA subsidies	-0.48 (0.52)	0.18 (0.17)	-0.09 (0.11)	-0.08 (0.06)	-0.27 (0.68)	0.13 (0.96)
Investment subsidies	1.10 (0.65)*	-0.38 (0.18)**	0.05 (0.07)	0.34 (0.26)	1.15 (0.81)	1.74 (1.06)*
Coupled subsidies	0.92 (0.43)**	-0.35 (0.14)**	0.07 (0.03) **	0.27 (0.15)*	0.69 (0.46)	1.07 (0.57)*
Direct payments	-0.63 (0.45)	0.24 (0.17)	-0.08 (0.04)**	-0.17 (0.13)	-0.22 (0.43)	-0.49 (0.62)
Single Farm Payment	-0.30 (0.54)	0.12 (0.19)	-0.06 (0.11)	-0.06 (0.08)	-0.13 (0.54)	-0.28 (0.79)
Subsidies per revenue	-2.00 (0.39)***	0.63 (0.09)***	-0.27 (0.06)***	-0.38 (0.06)***	-2.32 (0.47)***	-2.72 (0.69)***
Subsidies per hectare	0.13 (0.41)	-0.05 (0.16)	0.02 (0.06)	0.03 (0.10)	0.06 (0.43)	0.48 (0.64)
Parametric estimation	0.33 (0.37)	-0.13 (0.14)	0.06 (0.07)	0.07 (0.07)	0.72 (0.41)*	1.55 (0.96)
Bayesian estimator	0.70 (0.69)	-0.27 (0.24)	0.06 (0.03)**	0.21 (0.25)	-0.08 (0.59)	0.68 (0.75)
Quantile regression	-0.89 (0.68)	0.29 (0.16)*	-0.17 (0.12)	-0.12 (0.05)**	-1.21 (0.60)	-0.67 (0.74)
Tobit regression	-0.53 (0.53)	0.19 (0.17)	-0.10 (0.11)	-0.09 (0.06)	-0.17 (0. 58)	0.32 (0.81)
DEA output-orientation	-0.21 (0.50)	0.08 (0.19)	-0.04 (0.09)	-0.04 (0.09)	-0.11 (0.53)	0.43 (0.82)
Panel data	-0.73 (0.35)**	0.28 (0.13)**	0.07 (0.02) ***	-0.21 (0.12)*	-0.50 (0. 40)	-1.59 (0.74)**
EU area	-0.46 (0.33)	0.18 (0.12)	-0.06 (0.03)**	-0.12 (0.09)	-0.57 (0.32)*	-0.97 (0.44)**
North America	0.01 (0.66)	-0.004 (0.26)	0.002 (0.11)	0.002 (0.15)	-0.41 (0.70)	-0.38 (0.71)
Publication period	-1.27 (0.36)***	0.39 (0.07)***	-0.23 (0.06) ***	-0.16 (0.03)***	-1.53 (0.45)***	-1.74 (0.62)***
Publication status	-0.17 (0.35)	0.07 (0.09)	-0.03 (0.04)	-0.04 (0.05)	-0.05 (0.29)	-0.16 (0.50)
Cut1	-1.78 (0.79)**					
Cut2	-0.87 (0.73)					
Likelihood ratio	165.61***				105.38***	108.21***
Pseudo R-squared	0.28				0.39	0.49
% of correctly predicted obs.					82.05	85.62
Number of obs.	195				195	153

* significance at 10%; ** significance at 5%; *** significance at 1%

3.6 Conclusion

Predicting and investigating the impact of public subsidies on farms' technical efficiency are becoming critical issues in applied policy analysis. However, theoretical results on this issue are ambiguous and empirical findings in the literature are inconclusive. In this context, the objective of this chapter is to identify factors that could explain the heterogeneity of the observed empirical results.

In the empirical literature, the overall effect of agricultural subsidies on farm technical efficiency is significantly negative, but for 46% of the results provided in the existing studies, the effect is null (non-significant) or even significantly positive.

The meta-analysis of the sign of the effect reveals that when subsidies are modelled as output in the efficiency calculation, their effect on technical efficiency is commonly found to be positive. Using such a modelling approach may, however, give an erroneous view of subsidies' real influence on technical efficiency since there is no input increase associated with the additional output. In addition, proxying the subsidies considered by the ratio of the subsidies to farm revenue increases the probability of obtaining a significantly negative effect of subsidies on farms' technical efficiency. This probability is also increased, as evidenced by the meta-analysis, by using the ratio of subsidies to farm revenue instead of other subsidy proxies. A methodological recommendation is therefore that investigating the effect of subsidies on farms' technical efficiency should rely on a careful modelling of subsidies, and that, when possible, sensitivity analyses based on several modelling strategies should be carried out.

The other main finding highlighted by our meta-regression is that the period of publication (whether in journals or not) of the studies affects the direction of the subsidy-efficiency link obtained. More precisely, we find that studies published in 2003 or before are more likely to have reported a negative effect of subsidies on farms' technical efficiency than more recent studies. One reason may be the policy periods considered in the studies: earlier studies have mechanically focused on periods when decoupled subsidies were not fully on the governments' agenda, or farms were under less pressure from macro-economic conditions (such as price volatility). However, we have controlled for these two suggestions by testing in the meta-regression for the effect of specific types of subsidy and by including several dummy variables capturing the periods covered by the studies (not shown in the final specification used here). Another reason may be scientific progress in terms of methodologies. We find that the direction of the subsidy-efficiency link is robust to several methodological aspects included in our meta-regression, but there may be other methodological advances that we have not been able to capture in our meta-regression. A recommendation is therefore to continue to investigate the impact of subsidies on farms' technical efficiency using advanced techniques and multiple case studies, so that policy-makers are provided with tailored and more up-to-date findings.

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3.7 Appendix

Table 3.4 Overview of the empirical studies on the link between subsidies and farm technical efficiency

Reference	Study period	Location of the sample	Production sector	Sample size	Impact variable used: Type of subsidies	Impact variable used: Subsidy relative to:	Effect of the impact variable
Studies using DEA followed by a second-stage regression							
Bojnec and Latruffe (2013)	2004-2006	Slovenia	Crop, livestock	1784	Total operational subsidies	Subsidy rate (subsidies to farm output value)	-
Boussemart et al. (2012)	2005-2008	France	Crop	3337	Decoupled payment	Subsidies per hectare	+
Charyulu and Biswas (2010)	2009	India	Crop	46	Input and investment subsidies	Dummy	0
Desjeux and Latruffe (2010)	1990-2006	France	Crop	32781	Investment subsidies	Subsidies per hectare	+
					Coupled subsidies	Subsidies per hectare	-
					Environmental subsidies	Subsidies per hectare	-
					Decoupled payment	Subsidies per hectare	-
Desjeux and Latruffe (2010)	1990-2006	France	Dairy	20410	Investment subsidies	Subsidies per livestock unit	+
					Coupled subsidies	Subsidies per livestock unit	+/-
					Environmental subsidies	Subsidies per livestock unit	+
					Decoupled payment	Subsidies per livestock unit	+
Desjeux and Latruffe (2010)	1990-2006	France	Beef cattle	10003	Investment subsidies	Subsidies per livestock unit	0
					Coupled subsidies	Subsidies per livestock unit	-
					Environmental subsidies	Subsidies per livestock unit	-
Ferjani (2008)	1990-2001	Switzerland (valley)	Crop, livestock	12426	Direct payments	Subsidy rate (subsidies to gross margin)	-
Ferjani (2008)	1990-2001	Switzerland (hill)	Crop, livestock	6968	Direct payments	Subsidy rate (subsidies to gross margin)	-
Ferjani (2008)	1990-2001	Switzerland (mountains)	Crop, livestock	3713	Direct payments	Subsidy rate (subsidies to gross margin)	-
Fogarasi and Latruffe (2009)	2001-2004	France	Dairy	2716	Total subsidies	Subsidy rate (subsidies to output value)	-
Fogarasi and Latruffe (2009)	2001-2004	Hungary	Dairy	128	Total subsidies	Subsidy rate (subsidies to output) value	-
Fogarasi and Latruffe (2009)	2001-2004	France	Crop	3644	Total subsidies	Subsidy rate (subsidies to output) value	-
Fogarasi and Latruffe (2009)	2001-2004	Hungary	Crop	1112	Total subsidies	Subsidy rate (subsidies to output) value	-
Fousekis et al. (2001)	2009	Greece	Sheep	101	Not indicated	Subsidy rate (subsidies to total farm income)	-

Gaspar et al. (2007)	2004-2005	Spain	Crop, livestock	69	Total subsidies	Subsidy rate (subsidies to income)	-
Guyomard et al. (2006)	1995-2002	France	Crop	5800	CAP direct payments	Subsidy rate (subsidies to farm revenue)	-
Guyomard et al. (2006)	1995-2002	France	Beef cattle	816	CAP direct payments	Subsidy rate (subsidies to farm revenue)	-
Guyomard et al. (2006)	1995-2002	France	Dairy	2144	CAP direct payments	Subsidy rate (subsidies to farm revenue)	-
Lambert and Bayda (2005)	1995-2001	United States	Crop	378	Total subsidies	Value per farm	0
Latruffe et al. (2013)	2001	Hungary	Livestock	192	Not indicated	Subsidy rate (subsidies to farm revenue)	-
Latruffe et al. (2008)	2005	Romania	Crop	319	Subsidies for crop output	Subsidies per hectare	+
					Subsidies for seeds and pesticides purchase	Subsidies per hectare	-
Li et al. (2012)	2010	China	Crop	99	Public agricultural subsidies	Subsidies per hectare	-
					Investment subsidies	Dummy	+
Nastis et al. (2012)	2008	Greece	Alfalfa	40	CAP subsidies	Subsidy rate (subsidies to output value)	-
Sedik et al. (2000)	1991-1995	Russia	Crop	350	Total subsidies	Subsidy rate (subsidies to farm revenue)	-
Skevas et al. (2012)	2003-2007	The Netherlands	Crop	703	Crop subsidies	Value per farm	-
Studies using parametric (SFA) estimation							
Areal et al. (2012)	2000-2005	England	Dairy	25000	Environmental payment	Dummy	-
					Set-aside payment	Dummy	+
Bakucs et al. (2010)	2001-2005	Hungary	Crop, livestock	3210	Total subsidies	Subsidy rate (subsidies to output value)	-
Barnes et al. (2010)	1989-2008	England, Wales	Crop, dairy, livestock		Total subsidies	Subsidy rate (subsidies to gross margin)	-/0
Bojnec and Ferto (2011)	2004-2008	Slovenia	Crop, livestock	3353	Total subsidies	Value per farm	-
Bojnec and Ferto (2013)	2004-2008	Slovenia	Crop, livestock	1451	Total subsidies	Value per farm	-
Bojnec and Latruffe (2009)	1994-2003	Slovenia	Crop, livestock	130	Production subsidies	Subsidy rate (subsidies to revenue)	-
Brümmer and Loy (2000)	19987-1994	Germany	Dairy	5093	Farm credit program as investment subsidies	Dummy	-
Caroll et al. (2009)	1996-2006	Ireland	Dairy	3593	Decoupled subsidies	Dummy	-
Caroll et al. (2009)	1996-2006	Ireland	Cattle rearing	2087	Decoupled subsidies	Dummy	0
Caroll et al. (2009)	1996-2006	Ireland	Cattle finishing	2164	Decoupled subsidies	Dummy	0
Caroll et al. (2009)	1996-2006	Ireland	Sheep	890	Decoupled subsidies	Dummy	0
Caroll et al. (2009)	1996-2006	Ireland	Cereals	1016	Decoupled subsidies	Dummy	0
Chidmi et al. (2011)	2004-2008	United States	Dairy	1151	Total subsidies	Value per farm	+

Dinar et al. (2007)	1996	Greece	Crop, livestock	265	Total subsidies	Value per farm	0
Dung et al. (2011)	2009-2010	India	Crop	362	Total subsidies	Value per farm	-
Emvalomatis et al. (2008)	1996-2000	Greece	Crop	3614	Compensatory payments	Value per farm	-
Emvalomatis et al. (2008)	1996-2000	Greece	Cotton	1117	Compensatory payments	Value per farm	-
Giannakas et al. (2001)	1987-1995	Canada	Wheat	100	Government income transfer	Subsidy rate (subsidies to total farm income)	-
Hadley (2006)	1982-2002	England	Dairy	10597	Total subsidies	Subsidy rate (subsidies to gross margin)	+
Hadley (2006)	1982-2002	England	Sheep	4765	Total subsidies	Subsidy rate (subsidies to gross margin)	-
Hadley (2006)	1982-2002	England	Beef cattle	2846	Total subsidies	Subsidy rate (subsidies to gross margin)	+
Hadley (2006)	1982-2002	England	Poultry	578	Total subsidies	Subsidy rate (subsidies to gross margin)	0
Hadley (2006)	1982-2002	England	Pig	1459	Total subsidies	Subsidy rate (subsidies to gross margin)	0
Hadley (2006)	1982-2002	England	Cereals	4772	Total subsidies	Subsidy rate (subsidies to gross margin)	-
Hadley (2006)	1982-2002	England	Other crops	6461	Total subsidies	Subsidy rate (subsidies to gross margin)	-
Hadley (2006)	1982-2002	England	Mixed farming	7435	Total subsidies	Subsidy rate (subsidies to gross margin)	-
Iraizoz and Muniz (2004)	1989-1999	Spain	Livestock	398	Total subsidies	Subsidy rate (subsidies to farm revenue)	-
Iraizoz et al. (2005)	1989-1999	Spain	Beef cattle	2594	Total subsidies	Subsidy rate (subsidies to farm revenue)	-
Karagiannis and Sarris (2005)	1991-1995	Greece	Tobacco	1481	Total subsidies	Value per farm	-
Karagiannis and Sarris (2002)	1991-1995	Greece	Wheat	1480	Total subsidies	Value per farm	-
Karagiannis and Sarris (2002)	1991-1995	Greece	Mixed crops	1485	Total subsidies	Value per farm	-
Karagiannis and Sarris (2002)	1991-1995	Greece	Cotton	1475	Total subsidies	Value per farm	-
Karagiannis and Sarris (2002)	1991-1995	Greece	Olive	1481	Total subsidies	Value per farm	-
Karagiannis and Sarris (2002)	1991-1995	Greece	Fruits	1470	Total subsidies	Value per farm	-
Karagiannis and Sarris (2002)	1991-1995	Greece	Vegetables	1400	Total subsidies	Value per farm	-
Karagiannis and Sarris (2002)	1991-1995	Greece	Horticulture	1400	Total subsidies	Value per farm	-
Karagiannis and Tzouvelekas (2005)	1989-1992	Greece	Sheep	178	Total subsidies	Value per farm	0
Kroupová and Malý (2010)	2004-2008	Czech Republic	Crop	715	Total subsidies	Subsidies per hectare	-
Kumbhakar and Lien	1991-2006	Norway	Cereals	1512	Total subsidies	Value per farm	+

(2010)							
Kumbhakar et al. (2012)	2004-2008	Norway	Cereals	687	Coupled subsidies	Subsidy rate (subsidies to total farm net income)	-
				687	Environmental payments	Subsidy rate (subsidies to total farm net income)	-
Lachaal (1994)	1972-1992	United States	Dairy	/	Total subsidies	Value per farm	-
Lakner (2009)	1995-2005	Germany	Dairy	1348	Agri-environmental subsidies	Value per farm	-
Lambarraa and Kallas (2009)	2000-2004	Spain	Olive	315	LFA subsidies	Payment ratio (subsidies to total subsidies)	-
Lambarraa et al. (2009)	1995-2003	Spain	COP	9852	Policy reform (Agenda 2000)	Dummy	-
Latruffe et al. (2008)	2000-2004	Czech Republic	Dairy	431	Operational and investment subsidies	Value per farm	-
Latruffe et al. (2008)	2000-2004	Hungary	Crop, livestock	3210	Operational subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2008)	2000-2004	Slovenia	Crop	130	Production subsidies	Subsidy rate (subsidies to farm revenue)	-
Latruffe et al. (2012)	1990-2007	Belgium	Dairy	5017	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	Denmark	Dairy	8004	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	France	Dairy	21514	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	Germany	Dairy	30085	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	Ireland	Dairy	7578	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	Italy	Dairy	32120	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	Luxembourg	Dairy	3821	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	The Netherlands	Dairy	5017	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	Portugal	Dairy	9040	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	Spain	Dairy	22642	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	United Kingdom	Dairy	13119	Total subsidies	Subsidy rate (subsidies to output value)	-
Latruffe et al. (2012)	1990-2007	Belgium	Dairy	5017	Decoupled subsidies	Dummy	0
Latruffe et al. (2012)	1990-2007	Denmark	Dairy	8004	Decoupled subsidies	Dummy	-
Latruffe et al. (2012)	1990-2007	France	Dairy	21514	Decoupled subsidies	Dummy	+
Latruffe et al. (2012)	1990-2007	Germany	Dairy	30085	Decoupled subsidies	Dummy	+
Latruffe et al. (2012)	1990-2007	Ireland	Dairy	7578	Decoupled subsidies	Dummy	0
Latruffe et al. (2012)	1990-2007	Italy	Dairy	32120	Decoupled subsidies	Dummy	+
Latruffe et al. (2012)	1990-2007	Luxembourg	Dairy	3821	Decoupled subsidies	Dummy	0

Latruffe et al. (2012)	1990-2007	The Netherlands	Dairy	5017	Decoupled subsidies	Dummy	0
Latruffe et al. (2012)	1990-2007	Portugal	Dairy	9040	Decoupled subsidies	Dummy	0
Latruffe et al. (2012)	1990-2007	Spain	Dairy	22642	Decoupled subsidies	Dummy	+
Latruffe et al. (2012)	1990-2007	United Kingdom	Dairy	13119	Decoupled subsidies	Dummy	+
Malá (2011)	2004-2008	Czech Republic	Crop	390	Environmental subsidies	Subsidies per hectare	-
Malá (2011)	2004-2008	Czech Republic	Crop	390	Other subsidies	Subsidies per hectare	0
Mamardashvili and Schmid (2013)		Switzerland (plain)	Dairy	1362	Environmental subsidies	Subsidies per animal	+
Mamardashvili and Schmid (2013)		Switzerland (hill)	Dairy	2504	Environmental subsidies	Subsidies per animal	+
Mamardashvili and Schmid (2013)		Switzerland (mountain)	Dairy	1958	Environmental subsidies	Subsidies per animal	+
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	COP	309	Total subsidies	Subsidy rate (subsidies to farm revenue)	-
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	COP	309	Coupled subsidies	Value per farm	-
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	COP	309	Environmental subsidies	Value per farm	0
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	COP	309	LFA subsidies	Value per farm	0
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Dairy	3879	Total subsidies	Value per farm	-
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Dairy	3879	Coupled subsidies	Value per farm	+
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Dairy	3879	Environmental subsidies	Value per farm	+
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Dairy	3879	LFA subsidies	Value per farm	-
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Beef cattle	806	Total subsidies	Subsidy rate (subsidies to farm revenue)	-
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Beef cattle	806	Coupled subsidies	Value per farm	-
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Beef cattle	806	Environmental subsidies	Value per farm	+
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Beef cattle	806	LFA subsidies	Value per farm	0
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Pig	1487	Total subsidies	Subsidy rate (subsidies to farm revenue)	-
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Pig	1487	Coupled subsidies	Value per farm	-
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Pig	1487	Environmental subsidies	Value per farm	+
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Pig	1487	LFA subsidies	Value per farm	0
Manevska-Tasevska et al. (2013)	1998-2008	Sweden	Pig	1487	Investment subsidies	Value per farm	0

McCloud and Kumbhakar (2008)	1997-2003	Denmark	Dairy	2709	Total subsidies	Value per farm	+
McCloud and Kumbhakar (2008)	1997-2003	Finland	Dairy	1844	Total subsidies	Value per farm	+
McCloud and Kumbhakar (2008)	1997-2003	Sweden	Dairy	2053	Total subsidies	Value per farm	+
Piesse and Thirtle (2000)	1985-1991	Hungary	Cereals	819	Total subsidies	Value per farm	-
Rasmussen (2010)	1985-2006	Denmark	Crop, livestock	41926	Total subsidies	Value per farm	0
Rezitis et al. (2003)	1993-1997	Greece	Crop, livestock	482	Total subsidies	Value per farm	-
Sauer and Park (2009)	2002-2004	Denmark	Dairy	168	Organic subsidies	Value per farm	+
Serra et al. (2008)	1998-2001	United States	Crop	2196	Total subsidies	Value per farm	-
Sipiläinen et al. (2014)	1998-2001	Finland	Dairy	6341	Policy change	Dummy	0
Sipiläinen et al. (2014)	1998-2001	Norway	Dairy	5926	Policy change	Dummy	0
Sotnikov (1998)	1990-1995	Russia	Crop, livestock	450	Output subsidy	Value per farm	-
Thian and Wan (2000)	1983-1996	China	Indica rice	346	Investment subsidies	Value per farm	+
Thian and Wan (2000)	1983-1996	China	Japonica rice	224	Investment subsidies	Value per farm	0
Thian and Wan (2000)	1983-1996	China	Wheat	335	Investment subsidies	Value per farm	+
Thian and Wan (2000)	1983-1996	China	Corn	288	Investment subsidies	Value per farm	+
Zaeske (2012)	1985-2005	United States	Crop	240	Total subsidies	Value per farm	+
Zhu et al. (2012)	1995-2004	Germany	Dairy	12458	Coupled subsidies	Subsidy rate (subsidies to total income)	-
Zhu et al. (2012)	1995-2004	The Netherlands	Dairy	3223	Coupled subsidies	Subsidy rate (subsidies to total income)	-
Zhu et al. (2012)	1995-2004	Sweden	Dairy	3341	Coupled subsidies	Subsidy rate (subsidies to total income)	-
Zhu et al. (2012)	1995-2004	Germany	Dairy	12458	Livestock subsidies	Payment ratio (subsidies to total subsidies)	-
Zhu et al. (2012)	1995-2004	The Netherlands	Dairy	3223	Livestock subsidies	Payment ratio (subsidies to total subsidies)	-
Zhu et al. (2012)	1995-2004	Sweden	Dairy	3341	Livestock subsidies	Payment ratio (subsidies to total subsidies)	-
Zhu et al. (2012)	1995-2004	Germany	Dairy	12458	Input subsidies	Payment ratio (subsidies to total subsidies)	-
Zhu et al. (2012)	1995-2004	The Netherlands	Dairy	3223	Input subsidies	Payment ratio (subsidies to total subsidies)	-
Zhu et al. (2012)	1995-2004	Sweden	Dairy	3341	Input subsidies	Payment ratio (subsidies to total subsidies)	-
Zhu and Oude Lansink (2010)	1995-2004	Germany	COP	4755	Total subsidies	Subsidy rate (subsidies to farm revenue)	-
Zhu and Oude Lansink	1995-2004	The	COP	1966	Total subsidies	Subsidy rate (subsidies	-

(2010)		Netherlands				to farm revenue)	
Zhu and Oude Lansink (2010)	1995-2004	Sweden	COP	1009	Total subsidies	Subsidy rate (subsidies to farm revenue)	-
Zhu et al. (2011)	1995-2004	Greece	Olive	2492	Total subsidies	Subsidy rate (subsidies to farm revenue)	-
Zhu and Oude Lansink (2010)	1995-2004	Germany	COP	4755	Crop subsidies	Payment ratio (subsidies to total subsidies)	
Zhu and Oude Lansink (2010)	1995-2004	The Netherlands	COP	1966	Crop subsidies	Payment ratio (subsidies to total subsidies)	
Zhu and Oude Lansink (2010)	1995-2004	Sweden	COP	1009	Crop subsidies	Payment ratio (subsidies to total subsidies)	
Studies using correlation or comparative analysis							
Douarin and Latruffe (2011)	2001-2002	Lithuania	Crop	147	Total subsidies	Subsidies per hectare	-
Galanopoulos et al. (2011)	2011	Greece	Sheep, goats	106	Total subsidies	Value per farm	+
Gaspar et al. (2009)	2004-2005	Spain	Livestock	69	Total subsidies	Value per farm	-
Kleinhanss et al. (2007)	1999; 2000	Spain	Pig	255;249	Total subsidies	Value per farm	+
Kleinhanss et al. (2007)	1999; 2000	Spain	Beef cattle	1435;1543	Total subsidies	Value per farm	+
Kleinhanss et al. (2007)	1999; 2000	Spain	Sheep and goats	553;679	Total subsidies	Value per farm	+
Kleinhanss et al. (2007)	1999; 2000	Germany	Pig	355;355	Total subsidies	Value per farm	+
Kleinhanss et al. (2007)	1999; 2000	Germany	Beef cattle	604;604	Total subsidies	Value per farm	+
Quero (2006)	2002	Spain	Beef cattle	50	Livestock premium	Subsidy rate (subsidies to farm revenue)	-
Soares et al. (2001)	1996	Spain	Dairy	122	Coupled subsidies	Value per farm	+
Taylor et al. (1986)	1982	Brazil	Crop	433	Credit subsidies	Value per farm	0
Theodoridis et al. (2012)	2007-2010	Greece	Sheep	58	Total subsidies	Value per farm	+

Chapter 4

Dynamic stochastic analysis of the farm subsidy-efficiency link: Evidence from France[1]

Abstract

The existing literature on the subsidy-efficiency nexus is almost exclusively static and thus ignores the intertemporal nature of production decisions. To contribute to this literature, this chapter aims at shedding light on the relationship between public subsidies and farm technical efficiency, using a dynamic stochastic framework. This framework is applied to a sample of French farms over the period 1992-2011. The results indicate that public subsidies impact negatively farm technical efficiency. For comparison purposes, we also estimate the static counterpart of the dynamic model. As in the dynamic case, we find a negative link between public subsidies and farm technical efficiency; but the results suggest that the static model over-estimates the inefficiency scores and the marginal effects of public subsidies. However, for our sample of French farms, the estimated marginal effects are relatively small.

4.1 Introduction

In the European Union (EU), in quest of a symbiosis between agricultural support policies and farming sustainability, the financial support to farmers has been gradually moved away from market price supports to coupled direct payments (production-related payments) and decoupled direct payments to farmers (European commission, 2011). Compared to the market

[1]This chapter has been written in collaboration with Timo Sipiläinen (University of Helsinki, Department of Economics and Management, Helsinki, Finland).

price supports and the production-related payments, the decoupled payments were intended to have no influence on farmers' production decisions. However, Hennessy (1998) has theoretically demonstrated that the decoupled payments could alter farmers' production decisions through an income-stabilising effect. In addition, Ciaian and Swinnen (2009) mention that decoupled subsidies could influence farmers' production decisions by reducing production constraints in allowing farmers to cover operating costs, or in serving as collateral to credit access for credit constrained farmers.

Hence, due to the potential influence of any kind of subsidies on farmers' behaviour, a growing body of literature examines their impact on farmers' production decisions, in order to enlighten policy makers. The current chapter is rooted in this literature with a particular attention on the subsidy-efficiency link. The investigation of the subsidy-efficiency link is of crucial importance from a survival perspective of the agricultural sector (Shee and Stefanou, 2015). Indeed, it could inform policy makers on the extent to which subsidies drive the optimal use of resources and the competitiveness of farmers in the long-run (see European commission, 2009; Latruffe, 2010). In this view, it is worth mentioning that farms' survival depends mainly on farmers' ability to make efficient decisions over time (Choi et al., 2006). In this respect, an important issue of the existing studies on the subsidy-efficiency link is that they are almost exclusively based on a static view of the decision-making process[2] . Although the static framework provides useful insights for theoretical and empirical studies on efficiency analysis, it ignores some relevant practical aspects. Particularly, it ignores the time interdependence of production decisions (Serra et al., 2011), and thus provides only a limited view of productive efficiency (Sengupta, 1999). As a result, a dynamic framework seems to be necessary for analysing the subsidy-efficiency link. Along with the dynamic setting, the stochastic production conditions in which farms operate must be acknowledged.

The dynamic efficiency literature is mainly built upon the adjustment cost framework (see Tsionas, 2006; Stefanou, 2009). More concretely, it relies on the principle that efficiency improvement requires adjustment decisions and thus incurs decision-makers to support adjustment costs for quasi-fixed inputs, or variable input reallocation costs (see Tsionas, 2006; Choi et al., 2006; Rungsuriyawiboon and Stefanou, 2007; Stefanou, 2009; Serra et al., 2011; Emvalomatis, 2012). This suggests that production decisions for improving current technical efficiency level depend on adjustment costs of quasi-fixed inputs, or on the level of variable input reallocation costs. In this case, public subsidies could help farmers to support adjustment costs for quasi-fixed inputs or variable input reallocation costs, if they face binding credit or liquidity

[2]To our knowledge the paper by Skevas et al. (2012), is the only exception. However, this paper uses a two-stage approach which is questionable (Simar and Wilson, 2011). The two-stage approach assumes that the input-output set is not influenced by subsidies. This assumption contrasts with theoretical studies which state that subsidies may influence the input-output space (see Hennessy, 1998; Serra et al., 2006).

constraints (see Ciaian and Swinnen, 2009; Latruffe et al., 2010). Nonetheless, it is also recognised that adjustment decisions are generally postponable and can be influenced by the elasticity of intertemporal substitution (EIS) of the decision-makers (Pindyck, 1993; Lence, 2000). The EIS can be thought here as an indicator of the willingness of decision-makers to smooth their wealth over time (see Weil, 2002) through adjustment decisions. In this respect, since subsidies could help farmers to smooth their wealth over the states of nature and over time, they could distort the timing of adjustment decisions by distorting the EIS, and thus cause persistent technical inefficiency.

In this context, this chapter aims at shedding light on the relationship between public subsidies and farm technical efficiency, using a dynamic stochastic framework. The main novelty of the chapter lies in estimating the link between public subsidies and technical efficiency in a dynamic stochastic framework. The appealing feature of this framework is that it enables recovering the stochastic and dynamic nature of the agricultural production process. The next section provides a succinct review of the existing literature on the parametric dynamic efficiency analysis. Section 4.3 presents the conceptual framework. Section 4.4 introduces the methodological framework and describes the data used. Section 4.5 presents the empirical results. Section 5.6 draws concluding remarks.

4.2 Related literature

The dynamic efficiency concept is built upon the notions of intertemporal production technology and adjustment decisions for which figure 4.1 provides some insights.

Figure 4.1 Intertemporal production technology

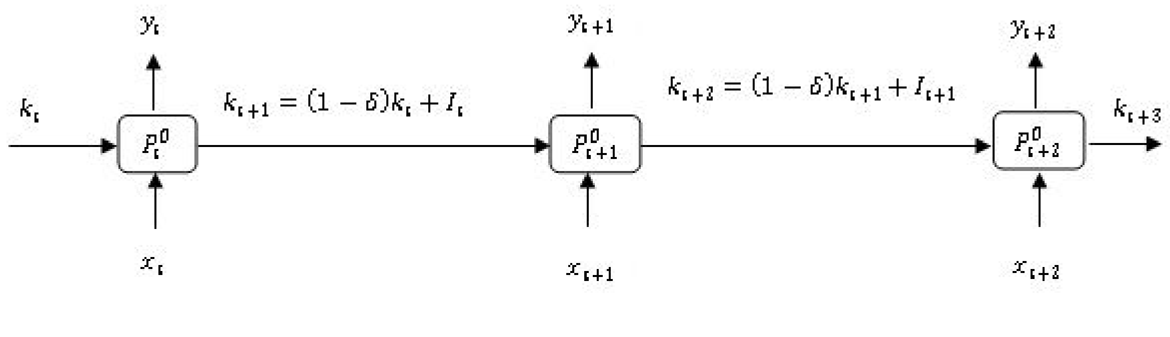


Figure 4.1 shows that, in period t, variable inputs x_t and quasi-fixed inputs k_t are transformed by the production process P_t^0 into output y_t and quasi-fixed inputs k_{t+1} which may include gross investments I_t. These new quasi-fixed inputs k_{t+1} and new variable inputs x_{t+1} constitute the main inputs for the production process P_{t+1}^0 in the subsequent period $t+1$. In this setup,

the intertemporal links are built upon the path of the quasi-fixed inputs. The path of these inputs is governed by the physical depreciation rate of capital δ and investment decisions I_t.

As previously stated, quasi-fixed input adjustment costs and variable input reallocation costs represent the core grounds of dynamic efficiency analysis (see, Choi et al., 2006; Stefanou, 2009; Serra et al., 2011). Adjustment or transition costs can be seen as transaction costs or reorganisation costs. Concretely, on the one hand, adjustment costs are additional costs that have to be supported by firms beyond acquisition costs (Stefanou, 2009). These costs may include credit costs, contractual costs, and learning or training costs. On the other hand, all variable inputs may not be instantaneously and costlessly reallocated to improve efficiency (Choi et al., 2006). This implies that, reallocation of variable inputs may require transition costs including learning or training costs and information search. It may also require a reorganisation or restructuring of the production activity, which may need adjustment of quasi-fixed inputs (Choi et al, 2006). Public subsidies could help farmers to support these costs, if they face binding credit constraints (see Ciaian and Swinnen, 2009 and Latruffe et al., 2010). But they may also distort economic pressures to adjust input use, since they could help farmers to smooth their wealth over the states of nature and over time.

In the econometric[3] literature, dynamic efficiency analysis is carried out using either reduced-form or structural dynamic models. The reduced-form dynamic models are mainly extensions of the standard stochastic frontier model through an autoregressive process of order 1 [AR (1)] for the inefficiency component (See Ahn et al., 2000; Tsionas, 2006; Emvalomatis, 2012; Galán et al., 2015). The dynamic structure of the reduced-form model relies on the AR (1) process for the inefficiency component which allows capturing inefficiency persistence. That is, it captures the part of the inefficiency that is transmitted from one period to the next. The inefficiency persistence is assumed to be related to high adjustment costs, sluggish adjustments, or uncertainty over future production conditions. From this viewpoint, Emvalomatis (2012) argues that the reduced-form dynamic models may allow capturing some dynamic aspects of firm's behaviour. However, since reduced-form dynamic models do not model explicitly the dynamic structure of the decision making process, explicit structural models may be preferable.

In the meantime, the existing parametric structural dynamic efficiency models include (i) the dynamic models developed by Rungsuriyawiboon and Stefanou (2007) and Rungsuriyawiboon and Hockmann (2015) based on the shadow cost approach and (ii) the dynamic model developed by Serra et al. (2011) based on the distance function approach. Basically, the shadow cost approach consists in relating actual observed costs to shadow (or behavioural) costs obtained from an optimisation programme. The connection is established through a distortion

[3]For the purpose of our analysis, we abstract from non-parametric dynamic efficiency models, since they are essentially deterministic (see Nemoto and Goto, 1999, 2003; Ouellette and Yan, 2008).

factor which captures departure from optimal values (the shadow cost approach is readily available in Stefanou and Saxena, 1988). The model by Rungsuriyawiboon and Hockmann (2015) is an extension of the one developed by Rungsuriyawiboon and Stefanou (2007) which allows accounting for multiple quasi-fixed factors. However, as stated by Serra et al. (2011) and recognised by Rungsuriyawiboon and Hockmann (2015), one issue of the shadow cost approach is that it does not specify the production technology directly. The structural model developed by Serra et al. (2011) is a dynamic directional input distance function derived from an intertemporal cost minimisation programme, given the duality between input distance functions and cost functions. Since distance functions may provide a complete characterisation of a production technology (Chambers et al., 1998), it appears that, to date, the more suitable parametric approach for dynamic efficiency analysis is the distance function approach developed by Serra et al. (2011). As such, in this chapter we follow a distance function approach.

4.3 Conceptual framework

We derive a dynamic efficiency model, based on the dynamic dual model of production decisions under uncertainty (Sckokai and Moro, 2009) and the duality between profit maximising input-output combinations and distance functions (Chambers et al., 1998). Indeed, following Sckokai and Moro (2009), we assume that farmers are risk averse and act so as to maximise an intertemporal utility function over an infinite horizon. The utility function is assumed to be concave and continuously differentiable. The farmers are further assumed to make decisions by drawing information from two state variables. The first state variable is a flow of capital services defined as net investments in quasi-fixed inputs k. The second state variable is a Gaussian random profit shock (ξ) due to the fact that the production process operates under uncertainty regarding input price, output price, and climatic effects. This disturbance is assumed to be independently and identically distributed over time, with zero mean and variance σ_{ξ}^2. In addition we assume that, for making their decisions, producers assimilate the variance of the random profit shock and the variance of their profit, $\sigma_{\xi}^2 = \sigma_{\pi}^2$. As a result, the discounted value of the utility of the farmers is given by:

$$J(.) = \max_{x_t, I_t} \int_0^{\infty} e^{-rt} U\left(\pi, \sigma_{\pi}^2\right) \qquad s.t. \qquad \dot{k} = (I - \delta k) \tag{4.1}$$

In this setup, r is the interest rate; t is the indicator of time; $U(.)$ is the utility function; $\dot{k}$ is the derivative of the capital path with respect to time; I is the gross investment; δ is the constant depreciation rate of the capital; and k is the unit of capital stock. The utility function depends on the expected wealth of the farm $\pi = \pi_0 + \bar{p}y - wx - ck + S$ and its variance σ_{π}^2. In the definition of the wealth, π_0 is the initial wealth of the farm, $y = f(x, k, I) + \varepsilon$ gives the intertemporal output production function of the farm, with a variance σ_y^2 , p is the market price of the output, which is a random variable with mean $\bar{p}$ and variance σ_p^2, implying that $\sigma_\pi^2 = f\left(\sigma_p^2, \sigma_y^2\right)$; w is the price of the variable inputs x; c is the rental price of the capital; and S are the public subsidies.

The Hamilton-Jacobi-Bellman equation associated with the producer's programme is given by:

$$rJ\left(.\right) = \max_{x_t, I_t} \left\{U\left(.\right) + J_k\left(I - \delta k\right)\right\} \tag{4.2}$$

Where rJ stands for the value of the stream of utility of farmers, and J_k denotes the shadow value of the capital. The first derivatives of [4.2] with respect to output and input prices yield the following system of equations for respectively output supply, investment demand, and variable inputs demand (Sckokai and Moro, 2009):

$$\begin{array}{rcl} y & = & U_\pi^{-1}\left[rJ_p - J_{kp}\dot{k}\right] \\ \dot{k} & = & J_{kc}^{-1}\left[rJ_c + kU_\pi^{-1}\right] \\ x & = & U_\pi^{-1}\left[rJ_w - J_{kw}\dot{k}\right] \end{array} \tag{4.3}$$

In this setup, a subscript denotes a first derivative, while a double subscript denotes a second derivative. If we assume that producers are technically efficient, in the sense that their input-output combinations are all optimal, their production decisions could be characterised by estimating expression [4.3]. However, since they do not always succeed in optimising their programmes (see Kumbhakar and Lovell, 2003), it is important to account for suboptimality or inefficiency in their production decisions. Following Chambers et al. (1998) and Serra et al. (2011), this can be done using distance functions.

Chambers et al. (1998) argue that distance functions may provide a complete characterisation of a production technology and allow modelling technical efficiency. Indeed, using duality theory, Chambers et al. (1998) show that profit-maximising input-output combinations can be represented by a directional technology distance function. On this basis, expression [4.3] could be alternatively defined using a dynamic directional technology distance function[4].

The dynamic directional technology distance function enables a simultaneous examination of output expansion, variable inputs contraction, and investment expansion. However, as pointed out by Serra et al. (2011), it may be quite difficult to account for the effect of exogenous drivers,

[4]In a similar way, Serra et al. (2011) derive a dynamic directional input distance function from intertemporal cost minimisation programme.

such as public subsidies, in a dynamic directional distance function. This may be related to the complex structure of the empirical model. To circumvent this issue, we define a simpler dynamic distance function, namely dynamic enhanced hyperbolic distance function, following Cuesta et al. (2009). The main difference between the directional distance function and the hyperbolic distance function is that the latter is based on the multiplicative homogeneity property of the Shephard's (1953; 1970) distance function, while the former is characterised by the translation property which is the additive analogue of the multiplicative homogeneity property (see Färe et al., 2005; Cuesta and Zofío, 2005; Cuesta et al., 2009, for more details).

Borrowing from Cuesta et al. (2009), the dynamic enhanced hyperbolic distance function can be expressed as follows:

$$D_E\left(y, x, , k, I\right) = \inf \left\{\phi >: \left({}^{y}\!/\!_{\phi}, x\phi, k\phi, {}^{I}\!/\!_{\phi} \right) \in T \right\} \tag{4.4}$$

where T represents all possible input-output combinations. The term hyperbolic reflects the hyperbolic path followed by the distance function toward the production frontier. As in Cuesta and Zofío (2005) and Cuesta et al. (2009), the range of the dynamic enhanced hyperbolic distance function is $0 < D_E\left(y, x, k, I\right) \leq 1$.

In expression [4.4], the dynamic links are mainly built upon the modelling of investment decisions, which allow accounting for adjustment decisions. In a sense, the modelling of investment decisions also allows accounting for adjustments of variable inputs. Indeed, as previously mentioned, in the dynamic world, technical efficiency analysis involves adjustments of variable inputs as well as adjustments of quasi-fixed inputs. In this line, it may be remarked from expression [4.3] that the variable inputs choice x is a function of the adjustments of the quasi-fixed inputs $\dot{k}$. This suggests the existence of a mapping between the adjustment of x and $\dot{k}$. On this basis, we may assume that the adjustment of all inputs depends on the adjustment of the quasi-fixed inputs.

4.4 Methodology and data

4.4.1 Methodology

To estimate the dynamic enhanced hyperbolic distance function defined in [4.4], we chose a stochastic translog specification since it complies with the almost homogeneity property of the hyperbolic distance functions (Cuesta and Zofío, 2005; Cuesta et al., 2009). For a case of Q outputs y, N variable inputs x, P quasi-fixed inputs k, H gross investments I, and M fixed inputs l, the stochastic translog specification is given by:

$$
\begin{aligned}
\ln D_{E_{it}}\left(y,x,k,I\right) = \quad & \alpha_0 + \sum_{q=1}^{Q} \alpha_q \ln y_{q,it} + \frac{1}{2}\sum_{q=1}^{Q}\sum_{q'=1}^{Q} \alpha_{qq'} \ln y_{q,it} \ln y_{q,'it} + \sum_{n=1}^{N} \alpha_n \ln x_{n,it} + \\
& \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{N} \alpha_{nn'} \ln x_{n,it} \ln x_{n,'it} + \sum_{p=1}^{P} \alpha_p \ln k_{p,it} + \tfrac{1}{2}\sum_{p=1}^{P}\sum_{p'=1}^{P} \alpha_{pp'} \ln k_{p,it} \ln k_{p,'it} \\
& + \sum_{h=1}^{H} \alpha_h \ln I_{h,it} + \frac{1}{2}\sum_{h=1}^{H}\sum_{h'=1}^{H} \alpha_{hh'} \ln I_{h,it} \ln I_{h,'it} + \sum_{m=1}^{M} \alpha_m \ln l_{m,it} + \\
& \frac{1}{2}\sum_{m=1}^{M}\sum_{m'=1}^{M} \alpha_{mm'} \ln l_{m,it} \ln l_{m,'it} + \sum_{q=1}^{Q}\sum_{n=1}^{N} \alpha_{qn} \ln y_{q,it} \ln x_{n,it} + \sum_{q=1}^{Q}\sum_{p=1}^{P} \alpha_{qp} \ln y_{q,it} \ln k_{p,it} \\
& + \sum_{q=1}^{Q}\sum_{h=1}^{H} \alpha_{qh} \ln y_{q,it} \ln I_{h,it} + \sum_{n=1}^{N}\sum_{p=1}^{P} \alpha_{np} \ln x_{n,it} \ln k_{p,it} + \sum_{n=1}^{N}\sum_{h=1}^{H} \alpha_{nh} \ln x_{n,it} \ln I_{h,it} + \\
& \sum_{p=1}^{P}\sum_{h=1}^{H} \alpha_{ph} \ln k_{p,it} \ln I_{h,it} + \sum_{q=1}^{Q}\sum_{m=1}^{M} \alpha_{qm} \ln y_{q,it} \ln l_{m,it} + \sum_{n=1}^{N}\sum_{m=1}^{M} \alpha_{nm} \ln x_{n,it} \ln l_{m,it} \\
& + \sum_{p=1}^{P}\sum_{m=1}^{M} \alpha_{pm} \ln k_{p,it} \ln l_{m,it} + \sum_{h=1}^{H}\sum_{m=1}^{M} \alpha_{hm} \ln I_{h,it} \ln l_{m,it} + \upsilon_{it}
\end{aligned}
\tag{4.5}
$$

Where υ_{it} is a symmetric error term representing the usual statistical noise and unexpected stochastic change in production environment; i denotes individual indices; and t represents time indices. Following Cuesta et al. (2009), this hyperbolic distance function must be almost homogeneous of degrees 1, -1, -1, 1. This property states that if the set of outputs is increased by a given proportion, the set of variable inputs is reduced by the same proportion, the set of quasi-fixed inputs is reduced by the same proportion, and the set of gross investments is increased by the same proportion, then the distance function will increase by that same proportion (see Cuesta and Zofío, 2005; Cuesta et al., 2009, for more details). The almost homogeneous property is the multiplicative analogue of the translation property used in Serra et al. (2011). This property is required for econometric estimation, since the dependent variable in expression [4.5] is a latent variable.

Choosing the q_0-th output for normalising in order to satisfy the almost homogeneity condition, we get the following empirical specification:

$$
\begin{aligned}
\ln D_{E_{it}}\left(\frac{D_{E_{it}}}{y_{q0,it}}\right) = \;& \alpha_0 + \sum_{q=1}^{Q}\alpha_q \ln y^*_{q,it} + \frac{1}{2}\sum_{q=1}^{Q}\sum_{q'=1}^{Q}\alpha_{qq'}\ln y^*_{q,it}\ln y^*_{q,'it} + \sum_{n=1}^{N}\alpha_n \ln x^*_{n,it} + \\
& \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{N}\alpha_{nn'}\ln x^*_{n,it}\ln x^*_{n,'it} + \sum_{p=1}^{P}\alpha_p \ln k^*_{p,it} + \frac{1}{2}\sum_{p=1}^{P}\sum_{p'=1}^{P}\alpha_{pp'}\ln k^*_{p,it}\ln k^*_{p,'it} \\
& + \sum_{h=1}^{H}\alpha_h \ln I^*_{h,it} + \frac{1}{2}\sum_{h=1}^{H}\sum_{h'=1}^{H}\alpha_{hh'}\ln I^*_{h,it}\ln I^*_{h,'it} + \sum_{m=1}^{M}\alpha_m \ln l_{m,it} + \\
& \frac{1}{2}\sum_{m=1}^{M}\sum_{m'=1}^{M}\alpha_{mm'}\ln l_{m,it}\ln l_{m,'it} + \sum_{q=1}^{Q}\sum_{n=1}^{N}\alpha_{qn}\ln y^*_{q,it}\ln x^*_{n,it} + \sum_{q=1}^{Q}\sum_{p=1}^{P}\alpha_{qp}\ln y^*_{q,it}\ln k^*_{p,it} \\
& + \sum_{q=1}^{Q}\sum_{h=1}^{H}\alpha_{qh}\ln y^*_{q,it}\ln I^*_{h,it} + \sum_{n=1}^{N}\sum_{p=1}^{P}\alpha_{np}\ln x^*_{n,it}\ln k^*_{p,it} + \sum_{n=1}^{N}\sum_{h=1}^{H}\alpha_{nh}\ln x^*_{n,it}\ln I^*_{h,it} + \\
& \sum_{p=1}^{P}\sum_{h=1}^{H}\alpha_{ph}\ln k^*_{p,it}\ln I^*_{h,it} + \sum_{q=1}^{Q}\sum_{m=1}^{M}\alpha_{qm}\ln y^*_{q,it}\ln l_{m,it} + \sum_{n=1}^{N}\sum_{m=1}^{M}\alpha_{nm}\ln x^*_{n,it}\ln l_{m,it} \\
& + \sum_{p=1}^{P}\sum_{m=1}^{M}\alpha_{pm}\ln k^*_{p,it}\ln l_{m,it} + \sum_{h=1}^{H}\sum_{m=1}^{M}\alpha_{hm}\ln I^*_{h,it}\ln l_{m,it} + \upsilon_{it}
\end{aligned}
\tag{4.6}
$$

Where $y^*_{q,it} = \frac{y_{q,it}}{y_{q0,it}}$; $x^*_{n,it} = x_{n,it} \times y_{q0,it}$; $k^*_{p,it} = k_{p,it} \times y_{q0,it}$; $I^*_{q,it} = \frac{I_{h,it}}{y_{q0,it}}$. Furthermore, denoting $\ln D_{E_{it}} := u_{it} \geq 0$, moving it to the right-hand side of the equation [4.6], and assuming that it is a function of exogenous drivers z_{it} including public subsidies, we get the following empirical model:

$$
\begin{aligned}
-\ln y_{q0,it} = \; & \alpha_0 + \sum_{q=1}^{Q} \alpha_q \ln y^*_{q,it} + \frac{1}{2}\sum_{q=1}^{Q}\sum_{q'=1}^{Q} \alpha_{qq'} \ln y^*_{q,it} \ln y^*_{q,'it} + \sum_{n=1}^{N} \alpha_n \ln x^*_{n,it} + \\
& \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{N} \alpha_{nn'} \ln x^*_{n,it} \ln x^*_{n,'it} + \sum_{p=1}^{P} \alpha_p \ln k^*_{p,it} + \tfrac{1}{2}\sum_{p=1}^{P}\sum_{p'=1}^{P} \alpha_{pp'} \ln k^*_{p,it} \ln k^*_{p,'it} \\
& + \sum_{h=1}^{H} \alpha_h \ln I^*_{h,it} + \frac{1}{2}\sum_{h=1}^{H}\sum_{h'=1}^{H} \alpha_{hh'} \ln I^*_{h,it} \ln I^*_{h,'it} + \sum_{m=1}^{M} \alpha_m \ln l_{m,it} + \\
& \frac{1}{2}\sum_{m=1}^{M}\sum_{m'=1}^{M} \alpha_{mm'} \ln l_{m,it} \ln l_{m,'it} + \sum_{q=1}^{Q}\sum_{n=1}^{N} \alpha_{qn} \ln y^*_{q,it} \ln x^*_{n,it} + \sum_{q=1}^{Q}\sum_{p=1}^{P} \alpha_{qp} \ln y^*_{q,it} \ln k^*_{p,it} \\
& + \sum_{q=1}^{Q}\sum_{h=1}^{H} \alpha_{qh} \ln y^*_{q,it} \ln I^*_{h,it} + \sum_{n=1}^{N}\sum_{p=1}^{P} \alpha_{np} \ln x^*_{n,it} \ln k^*_{p,it} + \sum_{n=1}^{N}\sum_{h=1}^{H} \alpha_{nh} \ln x^*_{n,it} \ln I^*_{h,it} + \\
& \sum_{p=1}^{P}\sum_{h=1}^{H} \alpha_{ph} \ln k^*_{p,it} \ln I^*_{h,it} + \sum_{q=1}^{Q}\sum_{m=1}^{M} \alpha_{qm} \ln y^*_{q,it} \ln l_{m,it} + \sum_{n=1}^{N}\sum_{m=1}^{M} \alpha_{nm} \ln x^*_{n,it} \ln l_{m,it} \\
& + \sum_{p=1}^{P}\sum_{m=1}^{M} \alpha_{pm} \ln k^*_{p,it} \ln l_{m,it} + \sum_{h=1}^{H}\sum_{m=1}^{M} \alpha_{hm} \ln I^*_{h,it} \ln l_{m,it} + \upsilon_{it} - u_{it}\left(z_{it}\right)
\end{aligned}
\tag{4.7}
$$

Where $u_{it} \sim \left|N\left(0,\sigma_u^2\right)\right|$ is a non-negative error term reflecting technical inefficiency. The econometric estimation of distance functions may be subject to endogeneity issues (see Atkinson et al., 2003; Färe et al., 2005; Sauer and Latacz-Lohmann, 2014). Hence to provide consistent estimates for our model, we follow Sauer and Latacz-Lohmann (2014) by regressing each right-hand side variable in [4.5] on its lagged value and on all other regressors. This generates fitted values that are then used to estimate expression [4.7]. Additionally, before applying the normalisation procedure to comply with the almost homogeneity property, each variable in expression [4.5] is divided by its geometric mean. This allows interpreting the estimated first-order parameters as elasticities at the sample mean and avoiding convergence issues (Cuesta et al., 2009).

4.4.2 Data description

The data used are extracted from the database of the French region Meuse from 1992 to 2011, and concern farmers who are voluntary enrolled in a regional accounting office so as to be guided in their management practices. These data are very similar to European Farm Accountancy Data Network (FADN); in fact, they are used to produce FADN data, but they are a bit more detailed than FADN data (they contain a few more variables). The original sample contains 12,455 observations. In our analysis, we consider only farms which stay in the sample for at least five[5] years. Additionally, we remove observations with missing values and use lagged values to account for endogeneity as indicated in section 4.4.1. Hence, the final dataset used is an unbalanced panel with 9,760 observations on 1,005 French farms. Our dataset includes information on farm production structure, farm financial results, and agricultural subsidies. The empirical applications are conducted using two outputs, one variable input, one quasi-fixed input, two fixed inputs, and some contextual factors. The intertemporal links are modelled using gross investment in capital.

The two outputs include crop and livestock production values measured in Euros. The variable input is defined as the value of intermediate inputs in Euros. The quasi-fixed input is the value of the farm capital in Euros. The total labour used (composed of 93% of family labour) in annual working units (AWU) which are full-time yearly equivalents, and the utilised agricultural area (UAA) in hectares, are assumed to be fixed inputs. The contextual factors include the total subsidy received by farmers (excluding investment subsidies) on a per hectare basis; a financial variable defined as the ratio of debt to assets; and a time trend variable. Since our dataset covers three reforms (or regimes) of the European Common Agricultural policy (CAP), we use dummy variables for capturing the effects of these reforms. In fact, initially, the CAP was based on market price supports which provide a minimum price (guaranteed prices) for commodities. In 1992, the CAP has undergone a first reform (the MacSharry reform) which initiates a reduction in the price support scheme in favour of direct payments to farmers, coupled to production decisions. In 2000, the CAP has undergone a second reform (the Agenda 2000) which pursues the reduction of the guaranteed prices in favour of an increase in the direct payments. The third reform of the CAP (the Luxembourg reform), adopted in 2003 and implemented in France in 2006, introduces a decoupling of the direct payments, but some payments are still linked to production. Hence, for the MacSharry reform, we create a dummy equal to one for the period 1992-1999, and zero otherwise. Concerning the Agenda 2000, we create a dummy equal to one for the period 2000-2005, and zero otherwise. As regards the Luxembourg reform, we create a dummy equal to one for the period 2006-2011, and zero otherwise. However, the use of the

[5] We assume that 2 or 3 years are insufficient to estimate a dynamic model. So, to take at least 4 years to estimate the model, it is necessary to choose farms that stay at least 5 years in the sample, because we use lagged variables to treat the endogeneity problem.

dummy variables for the periods of the implementation of the reforms could not necessarily reflect the causal effects of the reforms, given unobservable drivers that could affect production decisions in these periods. To circumvent this issue, we use, in preference, variables obtained from the interaction of the subsidy variable and the reform indicators.

All monetary values are expressed in 1992 constant Euros, using specific price indices from the French National Institute of Statistics and Economic Studies (INSEE). Summary statistics for the main variables used are presented in table 4.1. Notice that monetary values for inputs and outputs are widely used in efficiency analysis due to their availability. However, one should keep in mind that efficiency scores estimated using monetary values reflect a mixture of technical and allocative efficiency. To attenuate price effects, we have deflated the monetary values; but this procedure does not necessarily convert them to real physical quantities. However, as mentioned in Sipiläinen and Oude Lansink (2005) and Zhu et al. (2011), this procedure assumes that farmers face the same prices and allows recovering implicit physical quantities for inputs and outputs variables measured in value.

Table 4.1 Summary statistics for the main variables used

	Mean	**Std. Dev.**
Crop output (Euros)	99,659.06	73,981.25
Livestock output (Euros)	128,838	92,426.17
Capital(Euros)	253,919.1	160,041.2
Gross investment (Euros)	39,304.37	48,458.93
Intermediate consumption (Euros)	194,907.7	114,044.9
UAA (hectares)	187.87	99.73
Labour (AWU)	2.22	1.09
Subsidy per farm (Euros)	39,304.44	31,025.11
Subsidy per hectare	209.96	105.08
Debt to assets	0.39	0.63
MacSharry reform (dummy)	0.39	0.49
Agenda 2000 (dummy)	0.32	0.46
Luxembourg reform (dummy)	0.28	0.45
Number of observations	**9,760**	

4.5 Empirical results

Parameter estimates for the dynamic model are reported in table 4.2. As a baseline for comparisons, table 4.2 also reports parameter estimates for the static counterpart of the dynamic model. The dynamic model differs from the static model mainly by accounting for investment decisions. The first-order parameters for outputs, investments, and inputs are significant at the 1 percent level and have their expected sign. These parameters are estimated to be positive for outputs and investments, and negative for inputs. These results suggest that the monotonicity conditions of hyperbolic distance functions are fulfilled at the sample geometric mean (Cuesta and Zofío, 2005). Furthermore, in the dynamic case, they indicate that, as expected, the dynamic hyperbolic distance functions is non-increasing in inputs and non-decreasing in outputs and investments at the geometric mean of the data. Although the monotonicity properties of hyperbolic distance functions are often evaluated at the geometric mean of the data (see Cuesta and Zofío, 2005; Cuesta et al., 2009), here we also check it at all sample data point. We find that the monotonicity properties are fulfilled at 98.3% of the sample for the outputs, 98.3% for the investments, 62.8% for the utilised agricultural area (UAA), 100% for the labour and the intermediate consumption, and 99% for the capital. Similar issues have been found in Vu and Turnell (2012) and Henningsen et al. (2014). It is well known that regularity conditions can be imposed in translog (hyperbolic) distance functions using Bayesian techniques (see Griffin and Steel, 2007; Vu and Turnell, 2012). However, this is not straightforward here given the size of our sample (about 10 000 observations).

Table 4.2 Estimated parameter for the dynamic model and its static counterpart

	Dynamic model		Static model	
	Estimated value	**Std. Error**	**Estimated value**	**Std. Error**
Distance function				
Intercept	4.92E-02 ***	9.16E-04	1.10E-01 ***	2.45E-02
Output	1.59E-01 ***	1.06E-03	2.67E-01 ***	7.56E-04
Land	-8.38E-03 ***	2.24E-03	-4.16E-02 ***	2.68E-03
Labour	-1.92E-02 ***	1.16E-03	-1.28E-02 ***	1.82E-03
Intermediate inputs	-3.37E-01 ***	3.46E-03	-5.88E-01 ***	3.18E-03
Capital	-1.89E-01 ***	2.98E-03	-2.08E-03	1.44E-03
Investments	1.42E-01 ***	2.02E-03	/	/
Output x output	-7.94E-02 ***	1.93E-03	-1.06E-01 ***	1.31E-03
Output x land	-1.40E-02 ***	3.45E-03	-5.63E-03	3.76E-03
Output x labour	-2.25E-03	2.17E-03	-2.66E-03	2.68E-03
Output x intermediate inputs	7.22E-02 ***	3.22E-03	-7.35E-03 *	4.03E-03
Output x capital	-2.71E-03	2.91E-03	-9.10E-05	1.41E-03
Output x investment	1.86E-02 ***	1.18E-03	/	/
Land x land	3.68E-03	9.58E-03	8.92E-03	1.47E-02
Land x labour	1.15E-04	4.84E-03	1.83E-04	8.82E-03
Land x intermediate inputs	6.65E-02 ***	8.62E-03	-1.12E-02	1.42E-02
Land x capital	-6.47E-02 ***	6.91E-03	-8.03E-03	5.34E-03
Land x investment	5.93E-02 ***	2.58E-03	/	/
Labour x labour	-7.88E-03 **	3.27E-03	-9.23E-03	9.13E-03
Labour x intermediate input	5.18E-03	3.98E-03	4.33E-03	1.08E-02
Labour x capital	-5.73E-03 *	3.13E-03	2.17E-03	4.03E-03
Labour x investment	-9.06E-04	1.66E-03	/	/
Intermediate input x intermediate input	-5.11E-02 ***	7.93E-03	-3.54E-02 *	1.95E-02
Intermediate input x capital	1.70E-02 ***	4.97E-03	-9.35E-03	6.63E-03
Intermediate input x investment	-2.98E-02 ***	2.05E-03	/	/
Capital x capital	7.63E-03 **	3.41E-03	6.46E-04	1.88E-03
Capital x investment	1.95E-02 ***	1.44E-03	/	/
Investment x investment	-3.64E-02 ***	7.39E-04	/	/
Time trend	1.49E-03 ***	8.48E-05	2.51E-03 ***	4.12E-04
Inefficiency effects				
Intercept	-2.03 ***	3.91E-01	3.87E-02 ***	2.48E-02

Subsidy per ha	7.90E-04 ***	2.51E-04	1.05E-04 ***	6.77E-06
Agenda 2000 x Subsidy per ha	1.17E-03 ***	1.64E-04	5.11E-05 ***	4.57E-06
Luxembourg reform x Subsidy per ha	2.43E-03 ***	3.45E-04	-1.03E-05	1.38E-05
Debt to assets	9.20E-02 ***	1.29E-02	4.45E-03 ***	1.03E-03
Time trend	2.11E-02 ***	5.61E-03	1.31E-03 ***	4.53E-04
Number of observations		9,760		9,760
Mean technical efficiency (TE)		0.97		0.93
LR test (no inefficiency vs inefficiency)		841.58 ***		940.76***
LR test (static model vs dynamic model)			4507 ***	
Welch test comparing mean TE			194.19***	
Correlation between the two TE vectors	Pearson's correlation:	**0.27*****;	Spearman's correlation:	**0.38*****

* significance at 10%; ** significance at 5%; *** significance at 1%

The first likelihood ratio tests (LR tests: no inefficiency vs inefficiency) reject the null hypothesis of no inefficiency at the 1% significance level. This suggests the existence of significant technical inefficiency in production decisions of farmers in our sample. But, by comparing the static efficiency model with the dynamic one, under the null hypothesis of their equivalence, a further LR test confirms that the dynamic framework is more appropriate for analysing farmers' production. This confirms the relevance of the dynamic framework for analysing farmers' production decisions.

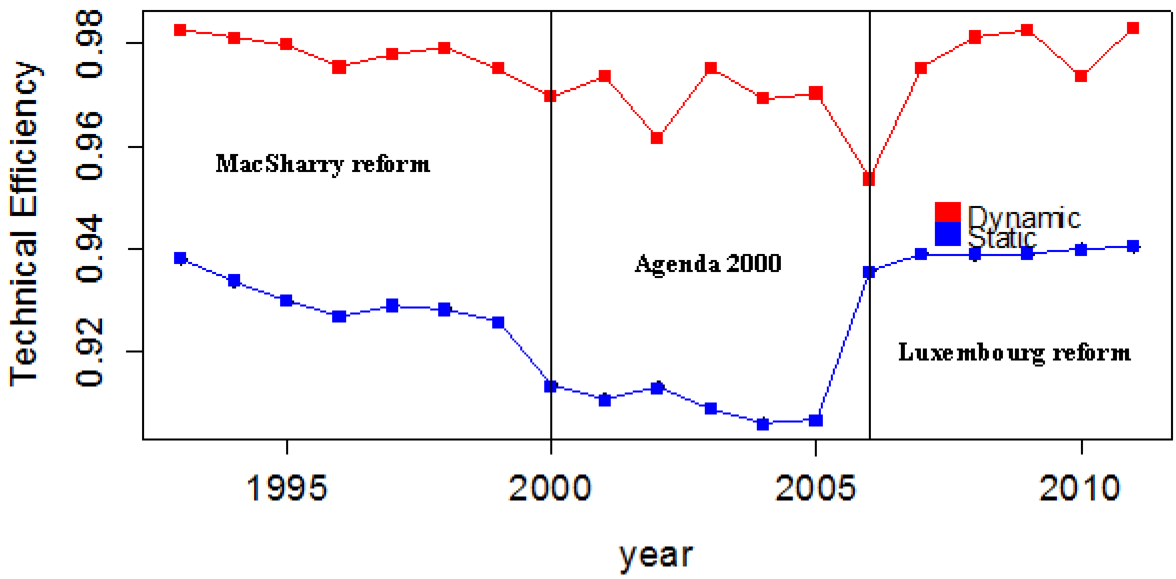
The average estimated dynamic technical efficiency score is of 0.97 while the static one is of 0.93. In the dynamic case, the estimated scores suggest that farmers, in our sample, could improve their technical efficiency level by 3 percent on average. In the static case, the estimated scores suggest that farmers could improve their technical efficiency level by 7 percent on average. Although the estimated efficiency scores are relatively close, a Welch test, reported in table 4.2, indicates they are significantly different. This suggests that, in our sample, the static model over-estimates the inefficiency scores. Similar results have been found in Dakpo and Oude Lansink (2015) in a nonparametric framework. This finding is also supported by table 4.3 and figure 4.2. In what concerns the dynamic model, table 4.3 shows that for 25% of the observations the efficiency scores are below 0.97 and that 75% of the observations have efficiency scores below 0.98. As for the static model, table 3 shows that for 25% of the observations the efficiency scores are below 0.91 and that 75% of the observations have efficiency scores below 0.94. On the other hand, the Spearman's rank-order correlation coefficients (0.38) and the Pearson's correlation coefficients (0.27), reported in table 4.2, show a quite weak positive link between the dynamic and the static technical efficiency scores. This suggests that there are considerable differences between the efficiency scores estimated by the the dynamic and the static model.

Table 4.3 Distribution and correlation of the two vectors of technical efficiency

	Min	1st quartile	Median	Mean	3rd quartile	Max
Dynamic	0.70	0.97	0.98	0.97	0.98	0.99
Static	0.83	0.91	0.93	0.93	0.94	0.96

Figure 4.2 indicates that the yearly averages of technical efficiency from the dynamic model are higher than those from the static model. On the other hand, for the dynamic model, figure 4.2 shows that, in comparison with the MacSharry reform and the Luxembourg reform, the estimated efficiency scores are lower for the Agenda 2000 reform. While for the MacSharry reform[6] and the Luxembourg reform the estimated efficiency scores are slightly different. A similar pattern is observed for the static model. However, one should keep in mind that these differences between the periods of policy reforms do not necessarily imply causal effects.

Figure 4.2 Yearly average of technical efficiency



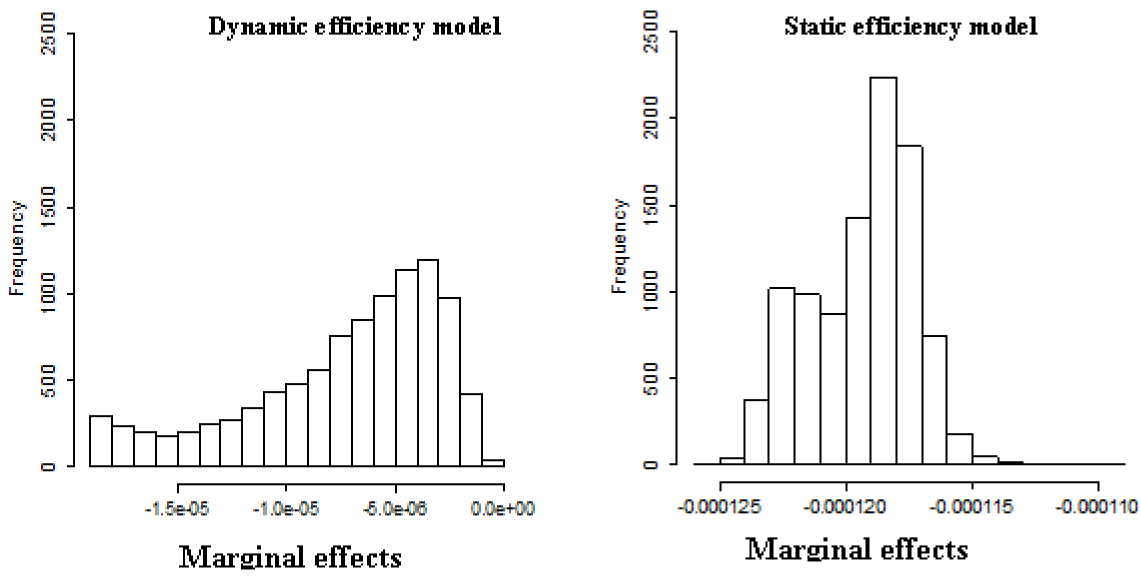
Regarding the effects of the contextual drivers, a positive (negative) sign indicates a positive (negative) association with technical inefficiency, and thus reveals a negative (positive) relationship with technical efficiency. In this respect, the estimation results for the dynamic model indicate that public subsidies impact negatively farm technical efficiency. This may be due to

[6] Recall that the MacSharry reform has initiated a reduction in the price support scheme in favour of direct payments to farmers, coupled to production decisions. The Agenda 2000 pursued the reduction of the guaranteed prices in favour of an increase in the direct payments. The Luxembourg reform introduced a decoupling of the direct payments, but some payments are still linked to production.

sluggish adjustments which potentially result from the fact that public subsidies could distort the timing of adjustment decisions. In a sense, this result supports the idea of Matthews (2013) who argues that "subsidies could slow down the rate at which resources are reallocated to more productive use in response to new technologies or market conditions". As in the dynamic case, the static model shows a negative link between public subsidies and farm technical efficiency. This result is consistent with earlier findings (e.g. Zhu and Oude Lansink, 2010; Kumbhakar et al., 2012; Bojnec and Latruffe, 2013; Sipiläinen et al., 2014). In this respect, our results suggest that public subsidies could distort optimal input use in a dynamic setting as well as in a static world. However, the marginal effects of public subsidies on the dynamic and the static technical efficiency plotted in figure 4.3 highlight that the static framework overestimates the effect of subsidies. However, it can be also seen from figure 4.3 that the marginal effect of public subsidies is relatively low: it is of the order 10^{-6} in the dynamic model and 10^{-4} in the static model. Using a dynamic data envelopment analysis (DEA), Skevas et al. (2012) have also found relatively small marginal effects for public subsidies (of the order 10^{-4}).

Simulation results, obtained from the estimated models, showed that the technical efficiency scores remained unchanged when subsidies were set to zero. In the same vein, the contribution of public subsidies to the variation of the estimated efficiency scores was found to be very small. It is of the order 10^{-7} in the dynamic model and 10^{-5} in the static model. These results highlight that the impact of subsidies on farm technical is negligible. This suggests that, in future research, authors have to estimate the real impact of subsidies on farm technical efficiency in the form of marginal effects instead of interpreting only the sign and the significance of the effects, as it is common practice in the existing empirical literature.

Figure 4.3 Marginal effects of public subsidies on farm technical efficiency



As for the agricultural policy reforms, the estimates reveal a significant negative effect of the agenda 2000 reform and the decoupling on technical efficiency within the dynamic model. In the static model a significant negative effect is found for the agenda 2000 reform, but the effect of the decoupling is not statistically significant. The findings from the dynamic model are confirmed by estimates for the time trend variable for which the estimated coefficient shows that technical efficiency decreases over time. Basically, this confirms the fact that even decoupled, public subsidies could distort production decisions. However, concerning the static model, although the effect of decoupling is not statistically significant, the estimates for the time trend variable show that technical efficiency decreases over time.

The results regarding indebtedness signal that the higher the debt to assets ratio, the lower the farm technical efficiency. Although the literature on the relationship between indebtedness and technical efficiency is inconclusive (see Davidova and Latruffe, 2007; Mugera and Nyambane, 2014), the inverse association found in the current study could be interpreted within the agency theory (Jensen and Mecklin, 1976). In fact, when establishing a loan contract, lenders often charge borrowers an extra premium, given moral hazard and adverse selection issues. As a result, farmers with high debt face high credit cost which may reduce their profitability. This may induce technical inefficiency in the sense that highly indebted farmers may not have access to more credit to finance intermediate inputs (see Davidova and Latruffe, 2007).

4.6 Concluding remarks

The current chapter investigates the relationship between public subsidies and farm technical efficiency using a dynamic stochastic framework. This framework allows accounting for the stochastic and dynamic nature of the environment in which farms operate. But, for comparison purpose, we also estimate a static frontier model. The dataset used for the estimations is a sample of French farms located in the French Region Meuse over 19 years.

In the dynamic case, as well as in the static case, the estimation results show that public subsidies impact negatively farm technical efficiency. In the static case, our results support previous research which highlights that public subsidies are generally detrimental to farms' technical efficiency. However, our dynamic model, which accounts for the stochastic and dynamic nature of the agricultural production process, suggests that the static framework overestimates the effect of public subsidies. This may be an interesting result for policy makers, since it reveals that the impact of subsidies on technical efficiency is smaller when dynamic aspects are taken into account. However, in our sample of French farms, the estimated marginal effects from the static and the dynamic model are relatively small.

In this chapter, we use a stochastic frontier approach in which risk and uncertainty are confounded with statistical noises (see O'Donnell et al., 2010; Nauges et al., 2011). An alternative approach could be the state-contingent production framework (Chambers and Quiggin, 2000), which explicitly models uncertain production conditions through a set of states of nature.

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Chapter 5

The role of decoupled subsidies in a multitasking agriculture providing ecosystem services[1]

Abstract

This chapter proposes a new theoretical rationale for the possible incentive effect of decoupled subsidies. Using a multitasking agency model, we show that having recourse to mixed payment, by introducing decoupled payments, could raise farmers' incentives to provide non-contractible environmental services. This model is then empirically tested using French farm-level data. Our empirical results show that if "pay-for-performance" payments through environmental contracts impact positively and significantly the adoption of contractible services, e.g. permanent grass strip, they have no significant (or a negative) effect on the adoption of non-contractible environmental services, e.g. crop diversification or mixed farming practices. In contrast, mixed payment through decoupled subsidies helps balancing incentives for contractible and non-contractible environmental services.

5.1 Introduction

From a socio-environmental point a view, agriculture is by its very nature multitasking. The farmer is expected to produce food for society, but also preserves biological and landscape diversity. Both objectives may be conflicting since the dominant production mode in agriculture generates negative externalities on the environment that may reduce both biological and landscape diversity. Decades of production-coupled subsidies have led to a substantive increase in

[1]This chapter has been written in collaboration with M'hand Fares (INRA, Unit AGIR, Toulouse, France).

agricultural production and productivity, but also to a biased-technology toward chemical inputs (fertilisers and pesticides) that have harmful impact on environment (biological diversity) but also animal and human health. To balance this effect and try to internalise the negative externalities, some part of the subsidies became more conditioned and the farmer may get these subsidies only if he is committed in an environmental contract that specifies the adoption of environmentally friendly practices and inputs and the payment is contingent to this adoption. However, farmers seem to be reluctant to these contingent or "pay-for-performance" contract (Espinoza-Goded et al., 2013), and this may explain why the adoption rate of environmental contracts is low.

The general literature on incentives recognises that selective payment for performance leads to difficulties when there are many tasks expected of a supplier, as this is the case in agriculture (Bolton and Dewatripont, 2005). The problem of multitasking refers to the challenge of designing incentives to make appropriate effort across multiple tasks when the desired outcomes for some tasks are more difficult to measure than others (Holmstrom and Milgrom, 1991). Precise metrics for farmer actions that promote environmental quality are notoriously difficult to quantify. Furthermore, there are obviously many dimensions of quality for environmental services provided by agriculture and the farmer.

Multitasking[2] implies that the social planner or the government (providing subsidies) should use pay-for-performance cautiously as long as environmental service is rewarded only partially or metrics are imperfect. In general, the less precise the measure of performance, the less pay-for-performance incentives should be used.

The simple model of agriculture multitasking developed in this chapter suggests an additional implication: the problem of multitasking further strengthens the argument of mixed payment, e.g. by introducing partial decoupling subsidies from production. Previous economic arguments for decoupled subsidies and mixed payment center on reducing farmer risk's aversion (Hennessy, 1998) or relaxing credit constraints (Goodwin and Mishra, 2006). We show that introducing decoupled subsidies may be socially efficient since they can balance incentives for effort across contractible and non-contractible environmental services. This relationship between both dimensions deserves attention, especially as more new environmental instruments and contracts include measures of farmer performance in payment. Indeed, our main finding is that mixed payment, through decoupled subsidies, lessens distortions in effort allocation when pay-for-performance is imperfect, thus promoting non-contractible environmental services.

[2]The multi-functionality of agriculture is the generic term, but we want to depart from the usual literature on multi-functionality in agricultural economics. In this literature, multi-functionality mainly refers to joint-production analysis. In this chapter, we use the multitasking approach of incentive contract (Holmstrom and Milgrom, 1991) to deal with the different (ecosystem) services that agriculture may provide.

What has not been shown in the previous literature on multitasking is the link between pay-for-performance and mixed payment. Applying this idea to agricultural multitasking, we show that moving away from coupled toward more decoupled subsidies (mixed payment) may promote effort on environmental non-contractible services. This theoretical proposition has been empirically tested using a French database and confirmed by the estimation of: (i) a reduced-form of the model (an extended seemingly unrelated regression (SUR) model), which accounts for continuous, dichotomic and polytomic decision variables, and (ii) a structural model.

The remaining sections are organised as follows. Section 5.2 reviews the related literature. Section 5.3 presents the theoretical model and in section 5.4 we test the empirical prediction of our theoretical framework on the incentive effect of mixed payment and decoupled subsidies. Section 5.5 brings some concluding remarks.

5.2 Related literature

Concerns about coherence between agricultural policies and the sustainability of the agricultural sector have motivated a large body of literature on the influence of agricultural supports on farmers' production decisions, particularly in terms of optimal input use, acreage decisions, agricultural production and environmental externalities. Today, production-related subsidies (also named coupled subsidies), decoupled subsidies, and agri-environmental payments represent the main forms of agricultural support granted to farmers (OECD, 2014). The coupled subsidies are given to maintain some specific crops in farming; the decoupled subsidies serve mainly to stabilise farms' revenue; and the agri-environmental payments are given to farmers who voluntarily subscribe to a programme of environmentally friendly farming practices. While the production specific payments (coupled subsidies) are known to induce distortions in production decisions (Young and Westcott, 2000), the effect of decoupled subsidies on production decisions is still under debate (Just and Kropp, 2013), and the uptake rate of the agri-environmental schemes remains relatively low (Guillem and Barnes, 2013; Espinosa-Goded et al., 2013).

Overall, initial research on decoupled subsidies supports that they do not provide incentives for production intensification (see Just and Kropp, 2013). In this sense, they appear to be environmentally friendly since it is well known that intensification of agricultural production may lead to environmental damages such as biodiversity loss, water pollution, and land degradation. However, further research show that decoupled subsidies may increase production by reducing farmers' risk aversion to engaging in risky production activities (Hennessy, 1998, Sckokai and Moro, 2006; Féménia et al, 2010) and by relaxing credit constraints (Goodwin and Mishra, 2006; Ciaian and Swinnen 2009). Nevertheless, in a review of literature, Bhaskar and Beghin

(2009) highlight that the effects of decoupled subsidies on production decisions are likely to be negligible. Additionally, Serra et al. (2011a) evidence that decoupled subsidies have only negligible impacts on farmers' production decisions. However, in a more recent study, Just and Kropp (2013) argue that decoupled subsidies may be as production distorting as direct production subsidies. The reasoning is that, to be entitled to support, farmers are constrained to produce eligible crops even though the profits associated with these crops decline relative to the profits of non-eligible crops. This may create production distortions, because in this case producers are not encouraged to respond to market signals.

In what concerns farm productivity and technical efficiency, which can be seen as indicators of input optimal use, theoretical studies predict mixed impacts of decoupled subsidies (see Rizov et al, 2013; Kazukauskas et al., 2014; Serra et al. 2008; Kumbhakar and Lien, 2010). Although empirical results are in line with the theoretical predictions, the most common finding is a negative effect (see Minviel and Latruffe, 2014a). In addition, some of the positive effects reported in the literature may result in artifactual modelling approaches (see Minviel and Latruffe, 2014b). This suggests that, in essence, public subsidies involve non-optimal use of production factors.

As for acreage decisions, Goodwin and Mishra (2006) find a positive association between decoupled subsidies and acreage for grain productions. However, they mention that a more general evaluation of decoupled subsidies on acreage decisions has to include non-crop (pasture, follow, and set-aside) use of farmland.

Regarding the issue of agri-environmental schemes, it is agreed that adoption of environmentally friendly farming practices (EFFP) is strongly driven by the environmental attitudes (environmental consciousness) and the ecological perceptions of the farmers (Wilson and Hart, 2000; Morris et al, 2002; Guillem and Barnes, 2013). However, possible barriers to the adoption of environmentally friendly practices include additional fixed costs and income foregone associated with these practices (Espinosa-Goded et al., 2013; Europa, 2015). In this view, the decoupled payments may potentially encourage EFFP since they serve mainly to flatten farmers' revenue. This coincides with the idea of Espinosa-Goded et al. (2013) who mention that lump sum payments would be efficient for the adoption of EFFP.

The previous discussion suggests that more theoretical and empirical work is needed to address the coherence between agricultural policies and the sustainability of the agricultural sector. A limitation of the above literature is that the description of the strategic decisions of farmers is relatively poor. On the one hand, the productivity and efficiency analyses are insightful as they reveal the extent to which public subsidies influence the optimal use of inputs. Nevertheless, in a socio-environmental perspective, they provide only partial insights for policy makers. For instance, they do not provide specific information on the influence of subsidies on the efficiency of land use and chemical input use, which may be relevant for policy makers. On the other hand, the models of acreage decisions ignore the fact that, given decoupled subsidies, farmers may adopt extensive production strategies by extending areas under cultivation while reducing chemical input use per unit area (Boussemart et al., 2011). In essence, one important issue, which is not explicitly addressed in the previous literature, is the multitasking nature of farmers' production decisions. On this basis, this chapter develops an agency multitasking model to address this issue.

5.3 The model

5.3.1 Set-up

In this section, we develop a simple model tailored to the agro-environmental setting. Consider a farmer who contracts with the planner or the government (Ministry of Agriculture) to provide multiple agricultural (ecosystem) services to society. Consumers are supposed to desire various ecosystem services - e.g. quantity and quality of food, less pesticides and fertilisers use, biological and landscape diversity preservation. Let Q represent the production of food outputs in quantitative terms, and e_i denote farmer's effort on environmental service i. Social benefits from ecosystem services, $V_i(Q, e_i)$, are increasing and concave in production and effort. The social planner utility from ecosystem services is the sum of benefits from each individual ecosystem service, i.e. $V(Q, e) = \sum_i V_i$.

Assume that the farmer effort e_i on environmental service i increases the social utility $V_i(Q, e_i)$ for a given level of production, at a decreasing rate[3]. That is, $\partial V_i(Q, e_i)/\partial e_i > 0$ and $\partial^2 V_i(Q, e_i)/\partial e_i^2 < 0$. Assume environmental effort increases the marginal benefit of each ecosystem service, i.e. $\partial^2 V_i(Q, e_i)/\partial e_i \partial Q > 0, \forall i$. Environmental service effort vector e generates a disutility $C(e)$ for the farmer, where $C(e)$ is increasing and convex in effort. Similarly, production of food generates a disutility $C(Q)$ for the farmer, where $C(Q)$ is increasing and convex in its argument. We suppose also that increasing one environmental effort increases the marginal cost of other efforts, i.e. $\partial^2 C/\partial e_i \partial e_j > 0, \forall j \neq i$.

Some farmer environmental effort on providing ecosystem services may be contractible. For example, the planner/government may decide to offer an environmental contract with a "quality bonus" for specific ecosystem services that may improve quality of the environment, such as

[3]We do not add a production effort in our simple model since we are specifically interested in analysing the impact of the optimal mix of production subsidies, coupled and decoupled, on the incentives to provide effort on environmental services, whether they are contractible or not. In a more general model, it would be interesting to introduce a production effort.

introducing permanent grass strip, fallow ... Assume the government pays the farmer ν_j per verifiable unit of effort e_j, with $j \neq i$, and where ν_j can be seen as "pay-for-performance" or "bonus payment".

The revenue of the farmer is a three component compensation scheme. First, a market revenue from the output Q sold on the market at a price P. Without loss of generality we suppose that $P = 1$. Second, subsidies from a "production contract" with production coupled subsidies (αQ) with $0 < \alpha < 1$ and decoupled subsidies (or fixed payments, F). In Europe, this "production contract" refers to the first pillar of the Common Agricultural Policy (CAP). To ensure the participation of the farmer to the contract, if the government decides to reduce coupled subsidies (αQ), it needs to increase the decoupled subsidies (F). Third, subsidies from an agri-environmental contract with payments for some specific effort in ecosystem services that may improve the environment ($\nu_i e_i$). Taking into account the production cost ($C(Q)$) and disutility of the environmental effort ($C(e)$), the profit Π of the farmer can be written as follows:

$$\Pi = F + (1 + \alpha)Q - C(Q) + \sum_i \nu_i e_i - \sum_i C(e_i) \tag{5.1}$$

We suppose that the farmer cares about the social environmental concerns V, as well as his own profit Π from producing output and environmental services. His utility is then

$$U = U^0(\Pi) + \lambda V \tag{5.2}$$

The higher λ , the more "benevolent" the farmer is (see Daly and Giertz, 1972; Bergstrom, 1999). A farmer who equally values environmental concerns and his own profit would have λ equal to one. We assume that farmers do care about environmental concerns (see Anderson, 1990; McCann et al., 1997; Karali et al., 2014), although the level of "benevolence" could be quite limited. U^0 denotes the private component of the farmer's altruistic utility function U. We also assume that farmer's utility is strictly concave.

The government is supposed to be able to specify a payment for each environmental service separately (such as a premium for fallow and one for permanent grass strip). Dimensions of ecosystem performance that are not explicitly rewarded are implicitly assigned a "price" of zero ($\nu = 0$). That is, the effort distortions that arise in the model do not stem from inability to target ecosystem services incentives on particular services.

5.3.2 Incentives with one environmental service

The government is supposed to maximise the net social surplus subject to a budget constraint:

$$Max_{<Q,e>} W = W_C - T + W_F \quad s.t. \quad F + \alpha Q + \nu e \leq S \tag{5.3}$$

where W_C denotes consumers' surplus, T represents the taxes, and W_F denotes farmers' surplus, which are given by:

$$\begin{cases} W_C & = \lambda V\left(Q,\ e\right) - Q \\ T & = F + \alpha Q + \nu e \\ W_F & = \Pi = Q + F + \alpha Q + \nu e - C\left(Q\right) - C\left(e\right) \end{cases}$$

S denotes the total subsidy amount that can be spent by the regulator. Substituting W_C, T and W_F in 5.3, the regulator's programme becomes:

$$Max_{<Q,e>} W = \lambda V\left(Q, e\right) - C\left(Q\right) - C\left(V\right) \quad s.t. \qquad F + \alpha Q + \nu e \leq S \tag{5.4}$$

The first order conditions (FOC) are given by:

$$\begin{cases} \lambda V_Q(Q^*, e^*) & = C'(Q^*) + \mu\alpha \\ \lambda V_e(Q^*, e^*) & = C'(e^*) + \mu\nu \end{cases} \tag{5.5}$$

where μ represents the strength of the budget constraint, Q^* and e^* denote the first-best levels of output and effort. Expression [5.5] indicates that the marginal value of the production Q, and the marginal value of the environmental service are higher than their respective marginal cost in the presence pay-for-performance in environmental quality effort ν and high-powered production subsidies. This implies that the regulator can promote environmental quality effort with high-powered pay-for-performance or with low-powered production subsidies, assuming that Q and e are substitutable.

Suppose the regulator cannot reward environmental service effort (because e is non-contractible). Then the regulator has only one instrument (α) to hit two targets (increasing production and environmental services). Assuming Q and e are substitutable, the non-contractibility of environmental service presents a dilemma: a high production subsidy rate α ensures production quantity provision but not environmental effort; low α promotes environmental service but also low production quantity. A mixed form of payment is likely to be optimal, to balance production output with environmental service. The regulator can solve the dilemma if e is contractible. Then production subsidies parameter α can be set appropriately to increase production output, while direct rewards for environmental service prevent production from adversely impacting environmental service.

5.3.3 Incentives with two environmental services

Consider now a two-environmental service model. The regulator contracts with a farmer to provide two kinds of environmental services. The contract includes a fixed payment F (decoupled subsidies), a share payment αQ (coupled subsidies), as well as incentive payments $\nu_1 e_1$ and $\nu_2 e_2$ to motivate efforts in environmental services 1 and 2. In the two-service model where $C(e) = C(e_1, e_2)$, effort on service 1 competes for the farmer attention with effort on service 2, so that a higher level of one effort increases the marginal cost of the other. Denoting partial derivatives with a subscript, the assumptions are thus $\partial C(e_1, e_2)/\partial e_1 = C_1 > 0, \partial C(e_1, e_2)/\partial e_2 = C_2 > 0, \partial^2 C(e_1, e_2)/\partial e_1^2 = C_{11} > 0, \partial^2 C(e_1, e_2)/\partial e_2^2 = C_{22} > 0$. Similar to the case of one environmental service, the programme of the regulator is given by:

$$Max_{<Q,e_1,e_2>} W = \lambda V_1(Q, e_1) + \lambda V_2(Q, e_2) - C(Q) - C(e_1, e_2) \qquad s.t. \quad F + \alpha Q + \nu_1 e_1 + \nu_2 e_2 \leq S \tag{5.6}$$

The FOCs of the social welfare maximisation for choice of production output and environmental service efforts are

$$\lambda \left[\frac{\partial V_1(Q, e_1)}{\partial Q} + \frac{\partial V_2(Q, e_2)}{\partial Q} \right] = C'(Q) + \mu\alpha \tag{5.7}$$

$$\lambda \left[\frac{\partial V_1(Q, e_1)}{\partial e_1} \right] = C_1(e_1, e_2) + \mu\nu_1 \tag{5.8}$$

$$\lambda \left[\frac{\partial V_2(Q, e_2)}{\partial e_2} \right] = C_2(e_1, e_2) + \mu\nu_2 \tag{5.9}$$

where μ represents the strength of the budget constraint.

Comparative statics show how the relationships between services lead to the multitasking problems and how mixed payment through decoupled subsidies can mitigate the adverse effects. First, increasing the share payment for production (coupled subsidies) induces the farmer to increase his production output ($\partial Q/\partial\alpha > 0$). Increasing incentive payment for the first environment service (ν_1) induces the farmer to exert more effort on that service ($\partial e_1/\partial\nu_1 > 0$) and to decrease effort on the other environmental service ($\partial e_2/\partial\nu_1 < 0$). That is, our model replicates standard results of the literature on multitasking (Holmstrom and Milgrom, 1991).

What has not been shown in the literature on multitasking, and the primary focus here, is the trade-off between pay-for-performance ($\nu_i > 0$) for some environmental service(s) and mixed-payment ($0 < \alpha < 1$). The following proposition articulates both results.

Proposition 1. *Suppose that the first environmental service is non-contractible (ν_1 is constrained to 0), whereas the second environmental service is contractible ($\nu_2 > 0$). We get two results:*

(i) classic multitasking effect: Incentive payments on the second service ($\nu_2 > 0$) causes the multitasking problem, i.e. the farmer reallocates effort from the first service ($\partial e_1/\partial \nu_2 < 0$) to the second service ($\partial e_2/\partial \nu_2 > 0$).

(ii) mixed-payment effect: Introducing mixed payment by decreasing the high-powered incentives for production, through decoupled subsidies, can restore some incentive for the first service ($\partial e_1/\partial \alpha < 0$). The underlying idea is that, as mentioned earlier, to ensure the farmer's participation to the production contract, if coupled subsidies are reduced (by decreasing α), decoupled subsidies must be increased.

Proof. See appendix for the derivation of the results.

Proposition 1 implies that moving away from coupled subsidies toward more decoupled subsidies, i.e. mixed payment by decreasing α, reduces the multitasking problem. That is, it is possible to restore incentives for the non-contractible environmental service. In the example that we consider in the empirical application below, the permanent grass strip environmental service may be measurable, and thus contractible, while environmental service from mixed farming (MF) and crop diversification (NC) may be more difficult to measure. Then, using high-powered pay-for-performance will distort farmer away form mixed farming or investment in crop diversification toward permanent grass strip service. Using mixed payment, by decreasing coupled subsidies and increasing the decoupled subsidies (F) reduces the distortion.

5.4 Empirical analysis

To test the empirical prediction of our Proposition 1, we use a farm-level database that collected from 2003 to 2011: (i) French farmers' decisions on production and environmental practices; and (ii) different components of the public subsidies received by these farmers. After a brief presentation of the data and the two empirical models used [5.4.1], we discuss the results of the econometric results [5.4.2].

5.4.1 Data and econometric models

Data and variables

We use an unbalanced panel dataset for French farms located in the French region Meuse over two sub-periods of policy implementation: 2003-2005 and 2008-2011. This segmentation allows evaluating the incentive effect of decoupled payments as in a natural experiment framework. In the period covered by the current study, direct payments to producers have become dominant in the European Union (UE) CAP budget and the agri-environmental payments have been strengthened. However, in the sub-period 2003-2005, all direct payments received by producers were coupled to their production decisions (coupled payments) while in the sub-period 2008-2011 the major part of the direct payments has been decoupled from production (decoupled payments). Notice that, in France the implementation of the decoupled payment schemes started in 2006. However, in our data set, no information is available on decoupled payments for the years 2006 and 2007; that is why these years are excluded in our analysis. The total number of observations is 1,049 for the sub-period 2003-2005 and 1,592 for the sub-period 2008-2011.

The data set is provided by a regional accounting office and contains information on farm production structure, on farm financial results, and on agricultural subsidies. More precisely, it contains information on crop areas, crop production in monetary values and in physical quantities, implementation of permanent grass strip, total expenditures on pesticides, fertiliser use in monetary values and in physical quantities, work hours and workloads, coupled and decoupled payments, payment for permanent grassland, headage, and number of crops. It also contains information on variables that may influence production decisions such as farmer's age (Age), the legal status of the farms (individual or company farms) (Indiv), and farm's indebtedness (Debt). For estimation purposes, the dataset was complemented with output price, fertiliser price, pesticide price, and labour price. For the output, the fertilisers, and the labour, the prices are computed by dividing monetary values by physical quantities. Farmers produce several outputs and their prices are potentially correlated. To circumvent correlation issues in the estimation procedure, the output price used in the regression is a mean price computed from the individual prices. Since no information is available on physical quantities of pesticides, we cannot compute their prices. Hence, as in Serra et al. (2011b) and Laukkanen and Nauges, (2014), we consider the pesticide price index as a proxy for pesticide price. A statistical summary for those variables is presented in table 5.1. All monetary values are expressed in 2003 constant Euros using the appropriate deflators.

Among the critical variables, we distinguish a set of decisions including production services such as chemical input use (Fert and Pest) in cropping to increase the agricultural yield and environmental services such as implementation of permanent grass strip (PG), crop diversity (NC), and mixed farming adoption (MF). The dependent variables in expression [5.10, the reduced-form model] concern therefore the use of chemical fertilisers ($Fert$), the use of chemical pesticides ($Pest$), the implementation of permanent grass strip (PG), the number of crops (NC), and mixed farming (MF). The dependent variables are related to decoupled payment

(S_D), coupled payment (S_c), contract payment for permanent grassland (S_{pg}) but also fertiliser (W_f) and pesticide price (W_p), total farm area (L), the ratio of wheat area to total farm area (Sh_{wheat}), farmers' age (Age), a binary indicator for individual farms ($Indiv$) versus partnership farms, and farmers' indebtedness ($Debt$) measured as the ratio of farmers' debt and capital assets. The control variable Sh_{wheat} is used to account for some induced effects of wheat. In fact, wheat is a very profitable crop and it is very demanding in fertilisers and pesticides. It may therefore influence the other choices of the producers.

The reduced-form approach

We first test Proposition 1 prediction by having recourse to a reduced-form approach. That is, we estimate the impact of the compensation scheme (coupled and decoupled subsidies (S_C and S_D), and pay-for-(environmental) performance (S_{pg}) on the decision to adopt production services ($Fert$ and $Pest$) and contractible (PG) and non-contractible services (NC and MF). To do so, we estimate the following system of equations:

$$\begin{array}{rcl} Fert &=& \alpha_0 + \alpha_1 S_D + \alpha_2 S_c + \alpha_3 S_{pg} + \alpha_4 X + \xi_1 \\ Pest &=& \beta_0 + \beta_1 S_D + \beta_2 S_c + \beta_3 S_{pg} + \beta_4 X + \xi_2 \\ PG &=& \gamma_0 + \gamma_1 S_D + \gamma_2 S_c + \gamma_3 S_{pg} + \gamma_4 X + \xi_3 \\ NC &=& \delta_0 + \delta_1 S_D + \delta_2 S_c + \delta_3 S_{pg} + \delta_4 X + \xi_4 \\ MF &=& \theta_0 + \theta_1 S_D + \theta_2 S_c + \theta_3 S_{pg} + \theta_4 X + \xi_5 \end{array} \tag{5.10}$$

where $X = \{W_F, W_P, L, Sh_{wheat}, Age, Indiv, Debt\}$ is the vector of other exogenous variables. In this setup, the system of equations [5.10] allows testing direct and indirect effects of different incentives on farmers' choices. For instance, the agri-environmental schemes serve mainly to engage farmers in specific environmentally friendly farming practices such as implementation of permanent grass strip, but they may also contribute to the production of ecologically sound commodities by reducing fertiliser use at farm level, or by encouraging mixed farming. The decoupled payments may balance incentives toward extensive farming and thus induce production of ecologically sound commodities by reducing chemical input use and distortion toward contractible environmental service (permanent grass strip).

The system of equations [5.10], in which some of the dependent variables are continuous (Fert, Pest, PG) while others are ordered (NC) and binary (MF), can be estimated by the mixed-process maximum likelihood procedure introduced by Roodman (2011). This procedure can be seen as a seemingly unrelated regression (SUR) model (Zellner, 1962) with continuous and discrete variables. In behavioural analysis, the SUR model combines a set of equations related to a set of individual decisions, assuming that equation residual errors may be correlated for an individual given unobservable drivers that may influence his decisions. More precisely, the SUR method estimates simultaneously a set of equations which share a common error structure with non-zero covariance, so that the parameters of each single equation take into account information provided by the order equations (Cadavez and Henningsen, 2012). The term SUR is used in the sense that there is no reciprocal causation between endogenous variables and the error terms are assumed to be correlated across equations. Each equation of the SUR model could be consistently estimated separately; but a simultaneous estimation is generally more efficient since it uses information from full covariance structure of the model.

The structural-form approach

Besides the reduced-form approach, we also estimate a system of structural equations from expression [5.1]. To derive this system of equations, which concerns only the continuous variables, we follow Lacroix and Thomas (2011) and Laukkanen and Nauges (2014), by writing the expression of the profit Π of the farmer as follows :

$$\Pi = \sum_{c} L_c(P_c Q_c + S_c) + L_{pg} S_{pg} - wx + S_D \tag{5.11}$$

Were L_c denotes land allocated to crop c; P_c stands for output production price; Q_c denotes output production per hectare; S_c and S_{pg} represent per hectare subsidy rates for crops and permanent grass strip (L_{pg}); x is vector of inputs and w represents their corresponding price; and S_D stands for the amount of decoupled payments. Maximising the profit function [5.11] under the constraint of total land available, $L_c + L_{pg} = L$, yields optimal land, output, and input decisions. The equations related to these decisions can be derived by applying Hoteling's lemma to a dual profit function ($\prod(P_c, w, S_c, S_{pg}, S_D, L)$). To be theoretically valid, the profit function has to be convex in prices, linearly homogeneous in prices, monotonic increasing in output prices, monotonic decreasing in input prices. To impose these conditions as well as the constraint on the available total land, the dual profit function is modelled using the normalised quadratic form (Lau, 1976). As in Lacroix and Thomas (2011) and Laukkanen and Nauges (2014), the normalisation is done by dividing the profit, prices and subsidies by the price of one input. For the purpose of our analysis, the inputs considered include fertiliser, pesticide, and labour; and the price of labour is used to normalise the profit function. Hence, the quadratic profit function is given by

$$
\begin{aligned}
\bar{\Pi} \;=\;& \alpha_0 + \alpha_1 \bar{P}_c + \alpha_2 \bar{S}_c + \alpha_3 \bar{S}_{pg} + \alpha_4 \bar{S}_D + \alpha_5 \bar{W}_f + \alpha_6 \bar{W}_p + \alpha_7 \bar{P}_c \times \bar{S}_c \\
& + \alpha_8 \bar{P}_c \times \bar{S}_{pg} + \alpha_9 \bar{P}_c \times \bar{S}_D + \alpha_{10} \bar{P}_c \times \bar{W}_f + \alpha_{11} \bar{P}_c \times \bar{W}_p + \alpha_{12} \bar{S}_c \times \bar{W}_f \\
& + \alpha_{13} \bar{S}_c \times \bar{W}_p + \alpha_{14} \bar{S}_{pg} \times \bar{W}_f + \alpha_{15} \bar{S}_{pg} \times \bar{W}_p + \alpha_{16} \bar{S}_D \times \bar{W}_f \\
& + \alpha_{17} \bar{S}_D \times \bar{W}_p + 0.5\alpha_{18} \bar{P}_c^2 + 0.5\alpha_{19} \bar{S}_c^2 + 0.5\alpha_{20} \bar{S}_{pg}^2 + 0.5\alpha_{21} \bar{S}_D^2 \\
& + 0.5\alpha_{22} \bar{S}_c \times \bar{S}_{pg} + 0.5\alpha_{23} \bar{S}_c \times \bar{S}_D + 0.5\alpha_{24} \bar{S}_{pg} \times \bar{S}_D + 0.5\alpha_{25} \bar{W}_f^2 \\
& + 0.5\alpha_{26} \bar{W}_p^2 + 0.5\alpha_{27} \bar{W}_f \times \bar{W}_p + \alpha_{28} \bar{P}_c \times L + \alpha_{29} \bar{S}_c \times L + \alpha_{30} \bar{S}_{pg} \times L \\
& + \alpha_{31} \bar{W}_f \times L + \alpha_{32} \bar{W}_p \times L
\end{aligned} \tag{5.12}
$$

Differentiating with respect to prices and unit of subsidies yields

$$L_c Q_c = \frac{\partial \bar{\Pi}}{\partial \bar{P}_c} = \alpha_1 + \alpha_7 \bar{S}_c + \alpha_8 \bar{S}_{pg} + \alpha_9 \bar{S}_D + \alpha_{10} \bar{W}_f + \alpha_{11} \bar{W}_p + \alpha_{12} \bar{P}_c + \alpha_{28} L \tag{5.13}$$

$$L_c = \frac{\partial \bar{\Pi}}{\partial \bar{S}_c} = \alpha_2 + \alpha_7 \bar{P}_c + \alpha_{12} \bar{W}_f + \alpha_{13} \bar{W}_p + \alpha_{19} \bar{S}_c + \alpha_{22} \bar{S}_{pg} + \alpha_{23} \bar{S}_D + \alpha_{29} L \tag{5.14}$$

$$L_{pg} = \frac{\partial \bar{\Pi}}{\partial \bar{S}_{pg}} = \alpha_3 + \alpha_8 \bar{P}_c + \alpha_{14} \bar{W}_f + \alpha_{15} \bar{W}_p + \alpha_{20} \bar{S}_{pg} + \alpha_{12} \bar{S}_c + \alpha_{23} \bar{S}_D + \alpha_{30} L \tag{5.15}$$

$$-x_f = \frac{\partial \bar{\Pi}}{\partial \bar{W}_f} = \alpha_5 + \alpha_{10} \bar{P}_c + \alpha_{12} \bar{S}_c + \alpha_{14} \bar{S}_{pg} + \alpha_{16} \bar{S}_D + \alpha_{25} \bar{W}_f + \alpha_{27} \bar{W}_p + \alpha_{31} L \tag{5.16}$$

$$-x_p = \frac{\partial \bar{\Pi}}{\partial \bar{W}_p} = \alpha_6 + \alpha_{11} \bar{P}_c + \alpha_{13} \bar{S}_c + \alpha_{15} \bar{S}_{pg} + \alpha_{17} \bar{S}_D + \alpha_{26} \bar{W}_p + \alpha_{27} \bar{W}_f + \alpha_{32} L \tag{5.17}$$

where $L_c Q_c$ denotes output supply, L_c stands for land allocated to crop production, L_{pg} represents land allocated to permanent grassland, x_f and x_p denote fertiliser and pesticide uses respectively. The upper bar indicates normalised profit, price, and subsidy variables. For the purpose of our analysis, equations [5.12], [5.13], [5.14], [5.15], [5.16], and [5.17] form the system of structural equations to be estimated after appending a disturbance term to each equation. Equations [5.12] to [5.17] form the conceptual basis of the structural model. However, following Lau and Yotopoulos (1971), Khan and Maki (1979), and Dupraz and Latruffe (2015) some contextual variables that condition the realisation of the profit could be included in the structural model. On this basis, as in the expression [5.10], we consider the following contextual variables: the ratio of wheat area to total area (Sh_{wheat}), farmers' age (Age), a binary indicator for individual farms ($Indiv$) versus company or partnership farms, and farmers' indebtedness ($Debt$) measured as the ratio of farmers' debt and capital assets.

Table 5.1 Brief summary statistics of the main variables used

Variable		2003-2005		2008-2011	
Name	Abbreviation	Mean	SD	Mean	SD
Fertiliser input (Kg)	Fert	7,638	5,153	4,354	3,343
Pesticide input (Euros)	Pest	11,227	6,053	18,985	13,548
Permanent grassland (ha)	PG	55.57	33.71	61.01	42.64
Coupled payment (Euros)	Sc	43,734	19,780	5,236	6,870
Decoupled payment (Euros)	S_D	/	/	51,425	26,511
Payment for permanent grass strip (Euros)	S_{pg}	520.15	2,041	636.92	1,818
Total farm area (ha)	L	131.49	51.68	187.70	96.91
Land allocated to crop (ha)	L_c	75.91	42.56	126.68	86.66
Output price (Euros/tone)	P_c	173.44	31.41	132.66	27.90
Share of area in wheat (%)	Sh_{wheat}	24	11	27	9
Fertiliser price (Euros/Kg)	W_F	0.54	0.15	0.89	0.24
Pesticide price (index)	W_P	1.01	0.01	1.07	0.02
Number of crops	NC	4.04	1.41	4.19	0.96
Labour price (Euros/hour)		5.26	2.97	7.07	4.68
Mixed farms (dummy)	MF	0.87	0.33	0.88	0.32
Profit (Euros)	$\prod$	121,937	55,551	122,996	81,783
Age (years)		40.46	9.52	44.24	8.58
Individual farm (dummy)	Indiv	0.38	0.48	0.21	0.40
Debt (debt to capital assets)	Debt	0.39	0.88	0.35	0.38
Number of observations		1,049		1,592	

5.4.2 Empirical results

The estimation results for the extended SUR model (expression 5.10) are reported in tables 5.2a and 5.2b, while the estimates for the main equations of interest from the structural model are presented in table 5.3. We report results for the two sub-periods: 2003-2005 and 2008-2011; as previously stated, this allows evaluating the possible incentive effect of decoupled payments as in a natural experiment framework. Most of the regressors have a significant impact on farmers' decisions at the 1 or 5 percent level. As regard the main variables of interest and the correlation coefficients for the error terms by pair of equations (ρ_{ij}), the estimates from the reduced form and the structural form tell globally the same story and the results correspond closely to our expectations. This feature is very interesting since the structural model has been used to confirm some results provided by the reduced-form model (the extended SUR model).

The correlation coefficients for the error terms by pair of equations (ρ_{ij}) can be interpreted as the effects of unobservables on the corresponding dependent variables (Wooldridge, 2010). But, in a multitasking setting these correlation coefficients may also be considered as indicators of jointness in the decision making process (Ahearn et al., 2006), or as indicators of complementarity (in cases of positive signs) or substitutability (in cases of negative signs) between pairs of equations (Baskaran et al., 2013). In our estimates, the high level of significance of this coefficient signals that several equations are highly interrelated and that the parameters of each single equation take into account information provided by the other equations (Cadavez and Henningsen, 2012).

In a multitasking perspective of production decisions, the signs of the correlation coefficients are globally as expected. For instance, the use of chemical inputs and implementation of permanent grassland appear to be negatively correlated. This suggests that the production service provided by chemical input use (fertiliser, pesticides) and the environmental service provided by permanent grass strip are substitute services. Otherwise, this negative association indicate that ecosystem services provided by a reduction in chemical input use and those provided by permanent grass strip are complementary.

Our main findings on the effect of subsidies confirm our theoretical prediction. They suggest that payments for permanent grass strip impact positively and significantly the choice of permanent grass strip but these payments have no significant effect on the reduction of chemical input use (production service). First, as expected, contract payments for permanent grass strip is significantly positively associated with the choice of permanent grass strip practice. This positive effect holds in the two sub-periods of policy implementation (see tables 5.2a, 5.2b and 5.3), even though in the period 2003-2005 environmentally friendly practices were not encouraged, given the coupled payment scheme. The estimates for contract payment for permanent grass strip also highlight the multitasking issue stated in proposition 1. Indeed, the estimated coefficients for contract payment for permanent grass strip (tables 5.2a, 5.2b and 5.3) indicate that these payments do not imply a reduction of chemical input use or an increase in non-contractible environmental services (crop diversification or mixed farming). In contrast, mixed payment, through decoupled subsidies, induce a reduction in chemical input use, and a significant and positive effect on some environmental services (crop diversification and mixed farming adoption).

Importantly, the decoupled direct payments are estimated to have a significant negative impact on chemical input (fertiliser and pesticide) use. The decoupled direct payments are lump sum payments granted to farmers to stabilise their revenue, without production requirements. This may explain why they do not encourage intensive use of fertiliser and pesticide. These results are in line with Serra et al. (2006) and Kassoum and Lefer (2013). In addition, our findings are in line with results obtained by Koundouri et al. (2009) from simulation exercises for fertilisers. But they contrast with Koundouri et al.'s (2009) simulation results for pesticides and the results obtained by Peckham and Kropp (2012). Another interesting finding is that our estimates indicate that decoupled payments impact positively the implementation of permanent grassland, mixed farming, and crop diversification. These results confirm partly our theoretical prediction in the sense that they suggest that decoupled payment helps to balance incentives for effort across ecosystem services (contractible and non-contractible). These results could also be related to the cross-compliance measures required to be eligible for decoupled payments (Jaraite and Kazukauskas, 2012). Jaraite and Kazukauskas (2012) argue that cross compliance measures could reinforce farmers incentives to act in an environmentally friendly way.

In what concerns the coupled payments, the estimates indicate that they have a nonsignificant effect on implementation of mixed farming in the sub-period 2003-2005, and that they influence positively the use of chemical input (fertiliser and pesticide) in the sub-period 2003-2005. However, in the period 2008-2011, they impact positively the use of fertilisers, but their impact on pesticides use is nonsignificant. Concerning the use of chemical inputs, our results are in line with Laukkanen and Nauges (2014).

Table 5.2a Empirical Estimates of the extended SUR model for the period 2003-2005

	Fertilizer	Pesticide	Permanent Grassland	Nomber of Crops	Mixed Farming
Fertiliser price	-7,317***	-4,956**	50.27***	1.85 ***	2.43 ***
	(1,837)	(2,270)	(12.82)	(0.65)	(0.81)
Pesticide price	3,290 **	3,507**	-24.11***	-0.62	-1.66***
	(1208)	(1493)	(8.43)	(0.42)	(0.55)
Decoupled payment	/	/	/	/	/
Coupled payment	4.08***	11.74***	-0.03***	0.004 ***	-5E-04
	(1.38)	(1.71)	(0.009)	(0.0005)	(7E-04)
Payment for PG	-3.68	-10.59	0.12 *	-0.008**	-0.009**
	(10.00)	(12.36)	(0.07)	(0.03)	(0.004)
Farm area	52.63***	76.15***	0.33 ***	0.008 ***	0.007 ***
	(1.95)	(2.40)	(0.01)	(0.0007)	(0.001)
Share wheat	26,923***	17,821***	-147.8***	1.34 ***	-0.85 **
	(859)	(1062)	(6.00)	(0.30)	(0.41)
Age	0.43	42.45***	-0.13 *	0.009 ***	-0.006
	(10.77)	(13.31)	(0.07)	(0.003)	(0.006)
Individual farms	822 ***	526 *	-2.95 *	0.16**	-0.25**
	(231)	(294)	(1.66)	(0.08)	(0.12)
Debt	-99.60	266 **	-0.53	-0.05	-0.14 ***
	(107)	(132)	(0.75)	(0.04)	(0.04)
Intercept	-8,128***	-10,268***	55.19***	/	1.07***
	(732)	(905)	(5.11)		(0.38)
Number of observations			1,049		
ρ_{12}(Fert-Pest)			0.32 ***		
ρ_{13}(Fert-PG)			-0.15 ***		
ρ_{14}(Fert-NC)			0.17 ***		
ρ_{15} (Fert-MF)			0.05		
ρ_{23} (Pest-PG)			-0.61 ***		
ρ_{24} (Pest-NC)			0.48 ***		
ρ_{25} (Pest-MF)			-0.12 ***		
ρ_{34} (PG-NC)			-0.45 ***		
ρ_{35} (PG-MF)			0.29 ***		
ρ_{45} (NC-MF)			0.45 ***		

* significance at 10%; ** significance at 5%; *** significance at 1%; ρ_{ij}: correlation coefficient for each pair of equations. Standard errors in brackets; PG:Permanent Grassland

Table 5.2b Empirical Estimates of the extended SUR model for the period 2008-2011

	Fertilizer	Pesticide	Permanent Grassland	Nomber of Crops	Mixed Farming
Fertiliser price	-1,856**	5218 *	12.98	-1.31***	-0.07
	(734)	(3005)	(13.33)	(0.49)	(0.81)
Pesticide price	4215***	-3745	-77.45***	-0.29	-2.49 **
	(870)	(3540)	(15.71)	(0.58)	(0.96)
Decoupled payment	-0.08 ***	-0.11 **	0.003***	3E-05 ***	8E-05***
	(0.01)	(0.05)	(0.0002)	(8.7E-06)	(1.7E-05)
Coupled payment	2.38**	5.67	-0.02	0.003 ***	1.9E-03
	(1.12)	(4.56)	(0.02)	(0.0007)	(1.2E-03)
Payment for PG	-0.13	-0.24	0.004***	-2E-04 ***	- 8.5E-05
	(0.08)	(0.32)	(0.001)	(5E-05)	(9.2E-05)
Farm area	31.03 ***	118.44***	0.12***	0.003 ***	-0.002***
	(0.60)	(2.45)	(0.01)	(0.0004)	(0.0007)
Share wheat	9838***	36,896 ***	-215.2 ***	-0.05	-4.59***
	(426)	(1732)	(7.68)	(0.28)	(0.45)
Age	23.13***	41.36 ***	-0.29***	0.0004	-0.0006
	(4.88)	(19.88)	(0.09)	(0.003)	(0.005)
Individual farms	138	667	-2.18	-0.12 *	-0.17
	(112)	(455)	(2.02)	(0.07)	(0.11)
Debt	2.53 **	2967 ***	-14.57 ***	-0.34 ***	-0.83 ***
	(106)	(431)	(1.91)	(0.07)	(0.11)
Intercept	-5170 ***	-15,666***	106.35***	/	3.14 ***
	(286)	(1,164)	(5.16)		(0.33)
Number of observations			1,592		
ρ_{12}(Fert-Pest)			0.48 ***		
ρ_{13}(Fert-PG)			-0.60 ***		
ρ_{14}(Fert-NC)			-0.01		
ρ_{15} (Fert-MF)			-0.36 ***		
ρ_{23} (Pest-PG)			-0.50 ***		
ρ_{24} (Pest-NC)			0.07 **		
ρ_{25} (Pest-MF)			-0.26***		
ρ_{34} (PG-NC)			-0.18 ***		
ρ_{35} (PG-MF)			0.61 ***		

ρ_{45} (NC-MF)	0.31***

* significance at 10%; ** significance at 5%; *** significance at 1%; ρ_{ij}: correlation coefficient for each pair of equations. Standard errors in brackets; PG:Permanent Grassland

Table 5.3 Estimation results of the structural model

	2003-2005				2008-2011			
	Fert (1)	Pest (2)	PG (3)	Lc (4)	Fert (1)	Pest (2)	PG (3)	Lc (4)
Output price	6.63 (9.19)	-11.23	-0.27	-0.17	17.67 ***	36.20 *	-0.11	1.72 ***
		(12.41)	(0.17)	(0.11)	(5.68)	(21.04)	(0.09)	(0.54)
Fertiliser	-5,080***	-1400	7.04	7.41*	-2,451 ***	1,856 *	-0.12	(13.63 ***
price	(1646)	(1441)	(9.62)	(4.39)	(642)	(1016)	(0.08)	(4.68)
Pesticide	-1,400	996.24	1.50	12.55 **	1856 *	-9,791 ***	-0.23	24.85
price	(1441)	(2203)	(11.68)	(5.30)	(1016)	(2989)	(0.32)	(16.66)
Decoupled	/	/	/	/	-0.12 ***	- 0.10 **	0.002 ***	- 0.05 **
payment					(0.01)	(0.05)	(0.0003)	(0.02)
Coupled	7.44 *	12.55 **	0.12	0.09 *	13.63 ***	24.85	0.005	-0.06
payment	(4.39)	(5.30)	(0.08)	(0.05)	(4.68)	(16.66)	(0.01)	(0.56)
Payment for	7.04 (9.62)	1.50	0.29 *	0.12	-0.12	-0.23 (0.32)	0.05 **	0.05
PG		(11.68)	(0.18)	(0.08)	(0.08)		(0.02)	(0.01)
Total farm	52.47 ***	77.1 5***	0.30 ***	0.57 ***	30.16 ***	112.70 ***	0.19 ***	0.99***
area	(1.96)	(2.52)	(0.05)	(0.03)	(0.61)	(2.36)	(0.01)	(0.08)
Share wheat	26,813 ***	18,013 ***	-153 ***	125 ***	9395 ***	34,659 ***	-158 ***	371 ***
	(865)	(1113)	(22.68)	(14.02)	(444)	(1721)	(11.60)	(66.65)
Individual	847 ***	836 ***	-4.98	11.51 ***	69.81	470 (455)	-2.15	-13.86
farm	(240)	(310)	(6.27)	(3.89)	(117.07)		(3.25)	518.17)
Age	-5.68	19.54	-0.07	0.07	16.65 ***	4.90 (18.88)	1.12 ***	4.23 ***
	(10.87)	(13.79)	(0.28)	(0.16)	(4.93)		(0.09)	(0.56)
Debt	-75.45	304**	-0.73	0.52	270.49 **	3,117 ***	-15.79 ***	13.36
	(108.07)	(139)	(2.86)	(1.78)	(110.82)	(430)	(3.08)	(17.44)
Intercept	-6,630 ***	-6,598 ***	51.21	-54.14***	-4,399	-11,532 ***	2.35 ***	-365 ***
	(633)	(814)	(18.18)	(9.82)	(275)	(1,054)	(0.43)	(28.32)
Number of observations	1,049				1,592			
ρ_{12}(Fert-Pest)	0.32 ***				0.48 ***			

ρ_{13} (Fert-PG)	- 0.15 ***	-0.56 ***
ρ_{14} (Fert-Lc)	0.28 ***	0.29 ***
ρ_{23} (Pest-PG)	-0.61 ***	-0.48 ***
ρ_{24} (Pest-Lc)	0.73 ***	0.23 ***
ρ_{34} (PG-Lc)	-0.82 ***	-0.14 ***

* significance at 10%; ** significance at 5%; *** significance at 1%; Lc: land allocated to crop; Fert: fertiliser; Pest: pesticide; PG: permanent grassland; ρ_{ij}: correlation coefficient for each pair of equations. Standard errors in brackets

Concerning the other (control) exogenous variables, the estimates in tables 5.2a, 5.2b and 5.3 provide many intuitive results. For instance, utilised agricultural area (total farm area) is estimated to have a positive effect on chemical use and on establishment of permanent grass strip. We find that debt influences positively the use of chemical inputs and negatively the of permanent grass strip. This suggests that indebted farmers tend to adopt less environmentally friendly practices. In addition, the positive effect of debt on chemical input use signals that indebted farmers tend to use more chemical input to ensure their yield and avoid defaulting on debt obligations. This result supports the findings by Peckham and Kropp (2012). As for individuals farms and the control variable Age, the results are inconclusive. The results from tables 5.2a, 5.2b and 5.3 also display that the share of land allocated to wheat is positively associated to the use of chemical inputs. The estimates from the structural model (table 5.3) indicate that land allocated to crop production is not influenced by output price in the period of the coupled subsidies (2003-2005) while a positive association is found in the period of the decoupled payments (2008-2011).

5.5 Conclusion

In this chapter, a theoretical model is developed to study the possible incentive effect of decoupled subsidies. To the extent that some ecosystem services in agriculture cannot be written into an environmental contract, multitasking problems will always plague farmer performance measurement and thus reduce the development of such services. We show that this dilemma of agricultural multitasking gives support in favour of mixed payment, through decoupled subsidies.

The traditional argument for incentive effect of decoupled subsidies runs as follows: using decoupled subsidies reduces the farmer's aversion toward risky activities (Hennessy, 1998; Sckokai and Moro, 2006; Féménia et al, 2010) or relaxes credit constraint (Goodwin and Mishra, 2006; Ciaian and Swinnen, 2009). This chapter adds the following argument: since pay-for-performance incentives are imperfect for rewarding some specific services, using mixed payment through decoupled subsidies helps to balance incentives for effort across ecosystem services. First, mixed payment can reduce the negative externalities of production (through pesticide and fertiliser use) by providing weaker incentives to produce. Second, when environmental services are non-contractible and costly to provide (crop diversification and mixed farming practices), pay-for-performance for contractible environmental services and mixed payment through decoupled subsidies should be used. This theoretical proposition has been empirically tested using a French database and confirmed by the estimation of a reduced-form model and a structural model.

In this chapter we do not consider risk and uncertainty aspects, while these aspects could be vital for analysing farmers' behaviours. For instance, they could influence agency relationship (Chambers and Quiggin, 2000). They could also be salient determinants of the use of chemical inputs (fertilisers and pesticides), which are generally perceived as risk-increasing or risk-decreasing inputs (Horowitz and Lichtenberg 1993, Rajsic, Weersink, and Gandorfer 2009, Ramaswami,1992). A further research avenue is therefore to extend our theoretical model to account for risk and uncertainty, or to include an indicator of risk aversion (defined as the ratio of insurance cost to total expenditures) in our empirical model as in Goodwin and Mishra (2006). Furthermore, we do not consider production effort in our simple model since we simply aim at analysing the impact of the optimal mix of subsidies, coupled and decoupled, on the incentives to provide effort on environmental services, whether they are contractible or not. In a more general model, it would be interesting to introduce a production effort.

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5.6 Appendix

Proof of proposition 1

This appendix derives the comparative static results describing how farmer's choices of output and effort respond to the payment incentives of the underlying compensation scheme for production output (αQ) and environmental services ($\nu_1 e_1$ and $\nu_2 e_2$). Recall that the regulator's objective consists in maximising the social welfare under a budget constraint:

$$Max_{<Q,e>} W = \lambda V_1(Q, e_1) + \lambda V_2(Q, e_2) - C(Q) - C(e_1, e_2) \qquad s.t. \quad F + \alpha Q + \nu_1 e_1 + \nu_2 e_2 \leq S \tag{5.18}$$

The FOCs for choice of output and environmental efforts are given in the main text (equations 5.7 to 5.9). Strict concavity of regulator's utility implies that the Hessian matrix H is negative definite, where H is given by

$$H = \begin{bmatrix} \lambda V^1_{QQ} & 0 & \lambda V^1_{Qe} & 0 \\ 0 & \lambda V^2_{QQ} & 0 & \lambda V^2_{Qe} \\ \lambda V^1_{Qe} & 0 & \lambda V^1_{Qe} - C_{11} & -C_{12} \\ 0 & \lambda V^2_{Qe} & -C_{12} & \lambda V^1_{ee} - C_{22} \end{bmatrix}$$

where λV^1_{QQ} denotes $\frac{\partial^2 V_1}{\partial QQ}$, λV^2_{Qe} denotes $\frac{\partial^2 V_1}{\partial Qe}$, and so forth.

We derive some inequalities that will be useful in the comparative statics. By assumption of concavity, the Hessian determinant is positive (fulfilling the second-order condition for maximisation), and the principal minors alternate in sign. This implies that $\lambda V^2_{QQ}[\lambda V^1_{QQ}(\lambda V^1_{ee} - C_{11}) - [\lambda V^1_{Qe}]^2] < 0$. Since $V^2_{QQ} < 0$:

$$\lambda V^1_{QQ}(\lambda V^1_{ee} - C_{11}) - [\lambda V^1_{Qe}]^2 > 0. \tag{5.19}$$

Similarly, since environmental services 1 and 2 are perfectly symmetric, we have:

$$\lambda V^2_{QQ}(\lambda V^2_{ee} - C_{22}) - (\lambda V^2_{Qe})^2 > 0 \tag{5.20}$$

Moreover, the Hessian could also be written as:

$$H2 = \begin{bmatrix} \lambda V^1_{ee} - C_{11} & -C_{12} & \lambda V^1_{Qe} & 0 \\ -C_{12} & \lambda V^2_{ee} - C_{22} & 0 & \lambda V^2_{Qe} \\ \lambda V^1_{Qe} & 0 & \lambda V^1_{QQ} & 0 \\ 0 & \lambda V^2_{Qe} & 0 & \lambda V^2_{ee} \end{bmatrix}$$

It follows from concavity that the principal minors of H2 also alternate in sign, so that the following three inequalities hold:

$$[(\lambda V^1_{ee} - C_{11})(\lambda V^2_{ee} - C_{22}) - [C_{22}]^2 > 0 \tag{5.21}$$

$$\lambda V^1_{QQ}\left[(\lambda V^1_{ee} - C_{11})(\lambda V^2_{ee} - C_{22}) - (C_{12})^2\right] - (\lambda V^2_{ee} - C_{22})[\lambda V^1_{Qe}]^2 < 0 \tag{5.22}$$

$$\lambda V^2_{QQ}\left[(\lambda V^1_{ee} - C_{11})(\lambda V^2_{ee} - C_{22}) - (C_{12})^2\right] - (\lambda V^2_{ee} - C_{11})[\lambda V^2_{Qe}]^2 < 0 \tag{5.23}$$

by symmetry of services 1 and 2.

As regard the second part of proposition 1, consider the effect of introducing mixed payment by decreasing the share payment for production (α), through the increase of decoupled subsidies, on the farmer's choice of the first environmental service. From (5.20), we have

$$\frac{\partial e_1}{\partial \alpha} = \frac{-\lambda V^1_{Qe}\left[\lambda V^2_{QQ})(\lambda V^2_{ee} - C_{22}) - (\lambda V^2_{Qe})^2\right]}{|H|} < 0 \tag{5.24}$$

where the numerator is negative by (5.20) and the denominator is positive by strict concavity of $W(Q, e_1, e_2)$. The other comparative statics are derived analogously as follows:

$$\frac{\partial Q}{\partial \alpha} = \frac{\lambda V^1_{Qe}\left[\lambda V^2_{Qe})C_{12}\right]}{|H|} > 0 \tag{5.25}$$

$$\frac{\partial e_2}{\partial \alpha} = \frac{\lambda V^1_{Qe}\left[\lambda V^2_{QQ})(-C_{22})\right]}{|H|} > 0 \tag{5.26}$$

$$\frac{\partial Q}{\partial \nu_1} = \frac{\lambda V^1_{Qe}\left[(\lambda V^2_{QQ})(\lambda V^2_{ee} - C_{22}) - (\lambda V^2_{Qe})^2\right]}{|H|} > 0 \tag{5.27}$$

$$\frac{\partial e_1}{\partial \nu_1} = \frac{-\lambda V^1_{QQ}}{|H|} > 0 \tag{5.28}$$

$$\frac{\partial e_2}{\partial \nu_1} = \frac{\lambda V^1_{QQ}\left[\lambda V^2_{QQ})(-C_{22})\right]}{|H|} < 0 \tag{5.29}$$

Chapter 6

General conclusions

6.1 Overview

The PhD thesis focuses on the impact of public subsidies on farmers' production decisions. Its specific objectives are twofold. First, the thesis endeavoured to improve the understanding on how public subsidies impact production decisions with a special focus on farm technical efficiency. Second, it intended to investigate the potential effects of decoupled subsidies on farmers' provision of productive and environmental services.

The impact of agricultural policies on farmers' behaviour is regularly scrutinised. This results mainly from the need to continuously change agricultural support policies in response to changes in economic, social and environmental conditions within which farms operate, and changes in societal expectations. A second motivation for such analyses is to assess whether policy instruments implemented achieve their goal, since they often generate unintended consequences (Grant, 2007). A number of studies have addressed the impact of public subsidies on farms' performance (productivity and efficiency); the type and level of production; the use of production factors, such as land and labour; investment decisions; and the allocation of family labour to on- and off-farm activities.

In this thesis a particular attention was devoted to the impact of subsidies on farms' technical efficiency. The subsidy-efficiency link is of crucial interest for policy makers because it could inform on the extent to which public subsidies influence efficient use of production factors in the agricultural sector, despite subsidies not being aimed at it explicitly. In this regard and in the context of the successive changes in agricultural policies, there exists a growing body of literature on the subsidy-efficiency nexus. A major issue of this stream of literature is the existence of a plethora of models in which the effect of subsidies on technical efficiency is treated in an ad hoc way, given the absence of clear conceptual guidance on how to incorporate subsidy in a production efficiency framework. Potentially, this may generate misleading results. In this respect, the first question addressed in the thesis was whether there is unambiguous evidence on the subsidy-efficiency nexus in the existing literature, and if not, whether there are methodological aspects that can explain the discrepancies. The purpose was to investigate the incidence of analytical choices made by authors (such as the way subsidies are modelled, the type of subsidy considered, the variables used to proxy subsidies) on the effect (positive, negative, or null) of public subsidies on farm technical efficiency. To answer this question, a unique dataset was gathered from a systematic review of the existing literature on the subsidy-efficiency link; and then, using this dataset, a meta-regression analysis was carried out in the third chapter of the thesis.

The systematic review revealed that in the empirical literature, subsidies are commonly negatively associated with farm technical efficiency. However, the meta-regression estimation results showed that the direction (significantly negative, significantly positive or non-significant) of the effects is sensitive to the way subsidies are modelled. For instance, when subsidies are modelled as additional output in the efficiency calculation, their effect on technical efficiency is commonly found to be positive. Using such a modelling approach may, however, give an erroneous view of subsidies' real influence on technical efficiency since there is no change in input associated with the additional output. In addition, when subsidies received are proxied by the subsidy rate (i.e., the ratio of subsidies to farm revenue), the subsidy-efficiency nexus is commonly found to be negative. This approach may be artifactual, since econometrically it corresponds, in a sense, to the regression of a given variable on its inverse. In fact, the variable that is generally used as output in the subsidy-efficiency analysis is farm revenue. A methodological recommendation drawn from this analysis is therefore that particular attention should be paid on how subsidies are modelled and incorporated into the models so as to avoid erroneous conclusions.

A second issue of the literature on the subsidy-efficiency link is that it is almost exclusively based on a static view of agricultural production decisions, while most agricultural production decisions are dynamic in nature. The thesis hence examined whether there are any gains in understanding the subsidy-efficiency nexus by moving from static to dynamic modelling. The idea was to explore whether dynamic aspects associated with farmers' investment decisions in quasi-fixed inputs matter in analyses of how public subsidies impact farm technical efficiency. To address this question, a dynamic stochastic frontier model was developed and estimated for French data in the fourth chapter of the thesis; for comparison purposes, the static counterpart of this model was also estimated. The dynamic model developed is an extension of the parametric hyperbolic distance function introduced by Cuesta et al. (2009) in which intertemporal production decisions are modelled by accounting for farmers' investment decisions.

The results from the dynamic stochastic analysis showed that there are some gains in understanding the subsidy-efficiency nexus by moving from static to dynamic modelling. Overall, by comparing the static efficiency model with the dynamic one, under the null hypothesis of their equivalence, a likelihood ratio test suggested that the dynamic framework was more appropriate for analysing the sampled farmers' production decisions. As regards the estimated efficiency scores, they were found to be higher within the dynamic model. Similar results have been found in Dakpo and Oude Lansink (2015) in a nonparametric framework. In what concerns the subsidy-efficiency nexus, the results suggested that the impact of subsidies on farm technical efficiency was smaller when dynamic aspects were taken into account. However, in our sample, the estimated marginal effects appeared to be relatively negligible, even though they were significant at the 1% level. Additionally, simulation results showed that the technical efficiency scores remained unchanged when subsidies were set to zero. In the same vein, the contribution of public subsidies to the variation of the estimated efficiency scores was found to be negligible. This suggests that, in future research, authors have to estimate the real impact of subsidies on farm technical efficiency in the form of marginal effects instead of interpreting only the sign and the significance of the effects, as it is common practice in the existing empirical literature.

Another element of the PhD thesis was to examine the role of decoupled subsidies in a multitasking agriculture providing ecosystem services. Although decoupled subsidies became the cornerstone of agricultural support policies, Just and Kropp (2013) pointed out that their (potential) impact on farmers' production decisions remains unclear. In fact, in the jargon of the World Trade Organization (WTO), decoupled subsidies have been conceptualised as green-box subsidies, i.e., as government payments that are production neutral. Nevertheless, theoretical and empirical studies show that decoupled subsidies could have direct and indirect influence on farmers' behaviour. But, some studies report that their effect on farmers behaviour is relatively small (see Bhaskar and Beghin, 2009, for a review of literature). In the debate over the impact of decoupled subsidies on farmers' production decisions, an area that has received little attention is the multitasking nature of farming activities. Based on this multitasking nature, the thesis investigated whether decoupled subsidies could be useful in promoting farmers' provision of environmental services, despite these subsidies not being designed as such. This question was addressed in the fifth chapter of the thesis, by developing a theoretical model based on the multitasking agency theory. This model was then tested on French farm data, using an extended version of the seemingly unrelated regression (SUR) model and a structural model.

The basic agency theory focuses on the design of incentives with which one economic agent, namely the "Principal", seeks to motivate another, namely the "Agent", to choose his activities on the behalf of the principal (Macdonald, 1984). In contrast to the basic agency theory which concentrates on the realisation of a single task, the multitasking agency theory assumes that the Agent's main task is multidimensional (Holmstrom and Milgrom, 1991). In this case, when effort on one task raises the cost of effort on other tasks, the Agent will focus his effort on measurable and compensated tasks at the expense of others. This may induce the multitasking issue which refers to a challenge for the Principal to design incentive systems that allow avoiding this kind of substitution between tasks. The multitasking issue could appear in agricultural production decisions. Farmers are expected to produce ecologically sound outputs and ecosystem services. Therefore, if they are paid for a given measurable environmental service, they would neglect the other services and the production of ecologically sound outputs given their costs. In this sense, the thesis examined the possible incentive effect of decoupled subsidies in a multitasking agriculture.

The theoretical model developed in the thesis is a multitasking agency model. In this model, the Principal is a social planner (the government), that gives some incentives to an Agent (the farmer) to choose some specific ecosystem services (production or environmental services) through a contract. The Principal is assumed to maximise a social welfare function. The Agent (the farmer) is assumed to maximise a strictly concave and continuously differentiable utility function where the arguments are the profit generated by the production process, the subsidies, and a parameter that captures farmer's benevolence. In this model, we derive some testable propositions on the optimal compensation scheme in the contract (subsidies structures, i.e. coupled and decoupled) and the farmer choice regarding the different ecosystem services at the farm level. The model highlighted that a mixed payment system (with more decoupled subsidies) could reduce the multitasking issue in farming activities. In this sense, the thesis contributed to the existing literature by proposing a new theoretical rationale for the possible incentive effect of decoupled subsidies. The theoretical model was tested on French data using an extended SUR model (Roodman, 2011) which accounted for continuous, dichotomic and polytomic decisions variables. Furthermore, some aspects of the theoretical model were empirically tested using the structural model developed by Lacroix and Thomas (2011) and Laukkanen and Nauges (2014). The empirical results showed that decoupled subsidies could help balance farmers' incentives for effort across environmental services (contractible and non-contractible). More precisely, the results showed that decoupled subsidies impacted positively the implementation of permanent grass strip, crop diversification, and mixed farming. In addition, they suggested that decoupled subsidies could contribute to decreasing the negative externalities of production through the reduction of pesticide and fertiliser use.

6.2 Methodological and policy conclusions

As regard the provision of consistent information to policy-makers and various stakeholders on the impact of public subsidies on farm technical efficiency, the thesis makes several methodological recommendations to improve future analysis on the issue:

- Subsidies should not be modelled as additional outputs. One argument against the validity of the approach that uses subsidy as an additional output is that it artificially inflates the farm output and this output increase is not accompanied by a change in the use of inputs. In this case, a subsidised farm will appear more technically efficient than a non-subsidised farm, everything else being equal, although the former farm does not effectively produce more output. By contrast, it could be argued that subsidies are a proxy for non-market output produced by farms. For example, for calculating total factor productivity of Swiss farms, Jan et al. (2012) use agri-environmental subsidies to proxy environmental services provided by farms. The authors explain that these subsidies are taken into account as they 'require an additional input usage in comparison with the sole act of production of agricultural commodities'. However, the economic argument against the use of subsidies as output is that they are not an output generated by the classic agricultural production technology.

- Subsidies should not be modelled as additional inputs. In chapter 2 the thesis gathers some proofs through the literature that demonstrate that subsidies may be used by farmers to partly purchase conventional inputs (land, labour, capital, intermediate inputs) that are generally included in an efficiency model. Thus modelling subsidies as inputs results in double counting.

- Subsidies should not be proxied by the subsidy rate (i.e., the ratio between the total subsidies received by farmers and farm revenue or farm output in value). This approach generates misleading results because it corresponds, in a sense, to the regression of a given variable on its inverse, since the variable generally used as output in the subsidy-efficiency analysis is the farm revenue.

- Dynamic analysis may be more appropriate, since results provided in this thesis suggest that the static analysis assimilates dynamic aspects to inefficiency.

- Marginal effects have to be estimated and interpreted. In fact, the common practice in the subsidy-efficiency literature which consists in interpreting the sign and the significance of the effects could be misleading. Indeed, the effects could appear to be highly statistically significant although they are of negligible magnitude.

A policy implication that can be drawn from the thesis is that the mixed payment system with more decoupled subsidies could ensure the coherence between agricultural policies and the sustainability of the agricultural sector. Indeed, the results provided here indicate that decoupled subsidies have the virtue to provide incentives to reduce the negative externalities of production (through reduction of pesticide and fertiliser use). At the same time, they could encourage the implementation of permanent grass strip, crop diversification, and adoption of mixed farming.

6.3 Limits of the thesis and suggestions for further research

This PhD thesis provides some methodological and theoretical contributions to the literature on the impact of public subsidies on farmers' production decisions. However, additional work has to be done to be more confident on the implication of these contributions. For instance, our dynamic stochastic model developed in chapter 4 and our theoretical model developed in chapter 5 have to be applied to other datasets. In a similar vein, other dynamic models, such as the model of Serra et al. (2011), could be estimated for comparison purposes. In addition, some shortcomings of this thesis should be underlined.

The simple theoretical model developed in chapter 5 could be extended to account for risk and uncertainty, which are inherent to agricultural production. In addition, as regard the estimation of the SUR model, there is no clear-cut consensus in the literature on the interpretation of the correlation coefficients for the error terms by pair of equations. Some authors interpret them as the effects of unobservables on the corresponding dependent variables (Wooldridge, 2010), while others consider them as indicators of jointness (complementarity or substitutability) in the decision making process (Ahearn et al., 2006; Baskaran et al., 2013; Dupraz and Latruffe, 2015). We believe that heterogeneity (effects of unobservables) has to be separated from complementarity or substitutability. Furthermore, we do not consider production effort in our simple model since we simply aim at analysing the impact of the optimal mix of subsidies, coupled and decoupled, on the incentives to provide effort on environmental services, whether they are contractible or not. In a more general model, it would be interesting to introduce a production effort. Finally, the model could be reassessed assuming that production and environmental services are complement. We assume in our model that they are substitutable, but some studies suggest that there may exist a degree of complementarity (e.g. Boussemart et al., 2011).

In chapter 3, we claim that we undertook a systematic review of the existing literature. Although it is practically impossible to avoid some omissions, we expect that we have accounted for the vast majority of the existing papers on the subsidy-efficiency nexus. In addition, in chapter 3 and chapter 4, the thesis provides methodological recommendations that can help improve the understanding of the relationship between public subsidies and farm technical efficiency. These recommendations could serve as guidance for further empirical research on the subsidy-efficiency nexus. However, it is well known that empirical studies have to be built on sound theoretical grounds. In this sense, the thesis does not deal with a major issue in the subsidy-efficiency nexus, since it does not provide any contributions to advance the existing theoretical framework. Indeed, theoretically predicting the impact of public subsidies on technical efficiency remains a challenging task since the existing theoretical models are very limited. There exist two theoretical models that are usually used to predict the impact of public subsidies on farm technical efficiency (subsidy-efficiency nexus). These are the managerial behaviour model introduced by Martin and Page (1983) for the industrial sector, and the static optimisation model under risk aversion developed by Serra et al. (2008) for the agricultural sector.

The model of Martin and Page (1983) is not really appropriate to predict the subsidy-efficiency nexus for at least two reasons. First, technical inefficiency is generally thought as a failure to optimise; it occurs as a consequence of managerial inability (or incapacity) due to lack of knowledge, imperfect anticipation, uncertainty, or high adjustment costs. The X-inefficiency essentially reflects the labour-leisure decision of the producer, but not his ability to use a production technology efficiently. It is based on the idea of non-optimising behaviours (i.e., it is not rooted in the neoclassical formalism); it occurs as a consequence of lack of motivation to work which involves managerial deficiencies (see Leibenstein, 1977, 1978; Button and Weyman-Jones, 1994). Second, if one assimilates X-inefficiency to technical inefficiency, under certain conditions, the model of Martin and Page (1983) predicts an inverse relationship between subsidies and technical efficiency, while empirical studies find mixed effects. The model of Serra et al. (2008) presents an apparent advantage over Martin and Page's (1983) model, as it includes risk and uncertainty in the analytical framework. Furthermore, it predicts mixed effects, which is consistent with what is observed empirically. However, Serra et al.'s (2008) model is a little unrealistic. In fact, while farms operate in a multivariate context, the model developed by Serra et al. (2008) is available only for a simple case of a single output and a single risk decreasing input. Additionally, a general critical issue in the efficiency literature is that technical efficiency and X-efficiency are empirically measured using the same tools (Data Envelopment Analysis or Stochastic Frontier Analysis). In this sense, in the empirical analyses, there is no clear idea on what is really measured. On this basis, there is a real need to refine the existing theoretical framework.

One of the main findings of the thesis is that decoupled subsidies could provide to farmers incentives for the provision of environmental services. This finding is at odds with literature results from the technical efficiency framework which commonly report that public subsidies are detrimental to the agricultural sector's performance. To shed more light on this issue, a question to be deeply investigated is the influence of public subsidies (particularly decoupled subsidies) on the efficient use of inputs having environmental impacts (such as chemical fertilisers and chemical pesticides). One possible framework to do that is the multi-directional conditional efficiency analytical (conditional MEA) framework[1] introduced by Baležentis and De Witte (2015). The traditional efficiency measures (Farell, 1957; Banker et al., 1984; Aigner et al., 1977; Meeusen, van den Broeck, 1977) provide aggregated technical efficiency scores, while the basic nonparametric MEA (Bogetoft and Hougaard, 1999) allows decomposing aggregated technical efficiency scores into input-specific efficiency scores. The conditional MEA framework (Baležentis and De Witte, 2015) further allows investigating input specific efficiencies from aggregated efficiency scores, and at the same time accounting for the influence of contextual drivers on these scores. The analysis of the subsidy-efficiency nexus with aggregated technical efficiency scores may mask some relevant virtues of agricultural subsidies. For instance, a subsidy-efficiency analysis may reveal that subsidies are detrimental to the agricultural sector only because of overcapitalisation. In contrast, the conditional MEA may allow investigating the influence of public subsidies on the efficient use of a particular input. Particularly, it may enable analysing the effects of public subsidies on the efficient use of inputs having environmental impacts (such as chemical fertilisers and chemical pesticides).

In chapter 4 the thesis has tried to detect if there is a link between changes in agricultural policies and the evolution of farm technical efficiency. In such an analysis, it may be interesting to distinguish between persistent (time-invariant) technical inefficiency and residual (time-varying) technical inefficiency (see Kumbhakar et al., 2014). Indeed, as argued in Kumbhakar et al. (2014) and Kumbhakar et al. (2015), residual inefficiency could change over time even in the absence of changes in farm management practices. In contrast, if there are no changes in factors, such as government policies or public subsidies, which may alter farm management practices, persistent inefficiency would not be changed. In this sense, it may be very informative to investigate whether changes in agricultural policies induce changes in farm persistent inefficiency.

Finally, it is recognised that risk and uncertainty are inherent to agricultural production and that subsidies may influence farmer's behaviour under uncertain production conditions. However, in chapter 4 the thesis used a stochastic production frontier in which risk and uncertainty are confounded with statistical noise (see O'Donnell et al., 2010; Nauges et al., 2011). The state-contingent production theory, which explicitly models uncertain production conditions through a set of states of nature, appears to be a very promising avenue (see Chambers and Quiggin, 2000, 2002; Quiggin and Chambers, 2006). More importantly, this framework may allow investigating how subsidised farmers actually act under uncertain conditions. Additionally, it may facilitate differentiating inefficiency from effects due to heterogeneous production environments (Chambers et al., 2015).

[1]The stochastic efficiency decomposition model introduced by Bravo-Ureta and Rieger (1991) could be also used.

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RÉSUMÉ

La thèse s'intéresse à l'impact des subventions publiques sur les décisions de production des agriculteurs. Elle analyse d'abord le lien entre subventions et efficacité technique des exploitations, puis examine les effets des subventions découplées sur la fourniture de services écosystémiques par les agriculteurs.

L'influence des subventions sur le comportement des agriculteurs est une question importante dans le contexte de réformes successives des politiques agricoles. Il existe une vaste littérature sur cette question, mais celle-là présente trois limites majeures. D'une part, la littérature sur le sujet spécifique du lien entre subventions et efficacité technique repose sur une pléthore de modèles empiriques qui traitent les subventions de façon ad hoc. De plus, cette littérature est presqu'exclusivement basée sur des modèles statiques, alors que les décisions de production sont essentiellement dynamiques. D'autre part, peu de travaux analysent le rôle des subventions découplées en considérant la nature multitâche de l'agriculture.

C'est pourquoi la thèse réalise tout d'abord une méta-analyse des résultats empiriques existants sur le lien entre subventions et efficacité technique, afin de contrôler les effets qui seraient dus aux méthodes utilisées. Les résultats indiquent que la modélisation des subventions comme outputs, ou l'utilisation du ratio subventions/revenu comme proxy, pourraient générer des résultats trompeurs. Ensuite, la thèse développe et estime un modèle de frontière dynamique ainsi qu'un modèle similaire mais statique. Les résultats montrent que le cadre statique surestime l'effet (négatif) des subventions sur l'efficacité technique. Enfin, la thèse développe et teste un modèle d'agence multitâche indiquant que les aides découplées peuvent inciter les agriculteurs à fournir des services écosystémiques.

Mots-clés : Politiques agricoles ; subventions publiques ; exploitations ; décisions de production; efficacité dynamnique ; théorie de l'agence multitâches.

ABSTRACT

Public Subsidies and Farmers' Production Decisions : A Micro-economic Analysis

The thesis focuses on the impact of public subsidies on farmers' production decisions. It first concentrates on the link between public subsidies and farm technical efficiency, and then investigates the potential effects of decoupled subsidies on farmers' provision of ecosystem services.

The influence of public subsidies on farmers' behaviour is an important policy question in the context of the successive reforms of agricultural policies. There exists an extensive literature on this question, but this literature has three main shortcomings. First, the literature on the specific topic of the subsidy-efficiency nexus relies on a plethora of empirical models in which subsidies are often treated in an ad hoc way. Second, this literature is almost exclusively based on static modelling, while most agricultural production decisions are dynamic in nature. Finally, in the literature on the incentive effects of decoupled subsidies, the multitasking nature of farming activities has received little attention.

The thesis addresses these issues, first, by undertaking a meta-analysis of the existing empirical findings on the subsidy-efficiency nexus, in order to control for effects arising from the various methodologies used. The results show that modelling subsidies as outputs, or using the ratio of subsidies to farm revenue as a subsidy proxy, could lead to misleading results. Then, the thesis develops and estimates a dynamic frontier model; for comparison purposes, the static counterpart of this model is also estimated. The results indicate that the static framework overestimates the (detrimental) effect of subsidies on farm technical efficiency. Finally, the thesis develops and tests a multitasking agency model, indicating that decoupled subsidies could raise farmers' incentives to provide environmental services and ecologically sound production.

Keywords: *Agricultural policy, public subsidies, farms, production decisions, technical efficiency, dynamic efficiency, multitasking agency theory.*

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